

The Basis of Physics

Nineteen Essays on the Structural Limits of Physical Law

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Preface

This book makes a narrower claim than its title might suggest, and I want to state the claim exactly before the essays begin.

It does not offer a new physics. It does not propose a new equation, predict a new measurement, or derive the value of any constant. What it offers is a reading of the physics that already exists: an account of why the deepest results of the last century have the shape they have, and of why certain projects that physics has pursued for as long cannot be completed, in the form in which they were set.

The reading rests on one structural result, the Incommensuration Theorem, which the Introduction states in full. The theorem concerns comparison, and it says that of the four compounds one can build from sameness and difference applied to content and context, only two conjunctions survive when they are applied absolutely: continuity with asymmetry, and symmetry with discontinuity. Perfect symmetry and perfect continuity cannot be had together. That is the whole of it. The essays are the consequences.

Some of those consequences are readings of results physics already holds. Bell's theorem, the failure of determinism as an epistemology, the incompatibility of general relativity with quantum mechanics, the impossibility of a faithful reversal of time: each of these, the essays argue, holds for a structural reason that the theorem identifies, and the reading is the claim. Others are exclusions. There is no superdeterministic completion of quantum mechanics; there is no signal across the boundary that the speed of light marks; there is no single theory in which the two great theories are made one perfected description. These go a step beyond reading, and they are stated as what they are: consequences of the structure of comparison that reach into physics, where a finding could contradict them.

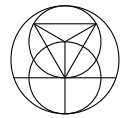
Each essay ends with a Summary, which says what the essay really is and opens with a statement of the kind of claim it makes: a claim of the metaphysics itself, a reading of known physics, or a structural exclusion. I have been exact about this because the subject invites inexactness. It is easy, when a structural argument lands on a familiar result, to let the argument seem to have done more than it did, and equally easy to credit it with less. The essays claim what they claim.

The volume rests on three foundation volumes. *Comparison; The Necessary Basis* sets out what comparison is, its six intrinsics, and the Root Tautology. *Incommensuration; The Theorem and the Three Axioms* proves the theorem from comparison alone and derives the three axioms from it. *Measurement; The Steps from Comparison to Physics* carries the ground into the measures of physics. Beside them stand the earlier volumes of the framework, *Third Resolutions in Western Philosophy*, *Unlocking Reality*, *Accessing the Real*, and *The Structure of Effective Choice*.

This book is the reading of physics, and it is the companion to the books of derivation. The derivations of physics from comparison, each step beyond the axioms stated as an identification, are made in *Measurement*, in *Non-Commutative Geometry and the Immanent Metaphysics*, where the algebra of the Standard Model's internal degrees of freedom is obtained from the structure of comparison, and in the physics volumes that follow them. This book does not repeat them. It reads the physics that already exists, which is where the framework meets the most exacting test: a body of results that were not made with it in mind, and that it must read without forcing. Whether it does is what each essay is for.

The essays can be read in any order, and the Introduction should be read first, since it fixes the terms and the modal alignment that every essay afterward assumes.

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Introduction: Physics at the Boundary of Comparison

What the Structure of Comparison Requires of Any Physics, and How to Read the Essays That Follow

ABSTRACT

This introduction sets out the terms and the results on which every essay in the collection depends. I begin with the Root Tautology, the recognition that interaction, comparison and relation are one act named three ways. So whatever is intrinsic to comparison is intrinsic to physics. I then set out the six intrinsics of comparison in their three pairs: sameness and difference; content and context; the subjective and the objective. I build four compounds from the intrinsics (symmetry, asymmetry, continuity and discontinuity), and I state the Incommensuration Theorem in full. The Incommensuration Theorem says that, of the ten pairings of the four compounds applied absolutely and together, symmetry with continuity and asymmetry with discontinuity are forbidden, while continuity with asymmetry and symmetry with discontinuity survive. I set out the three axioms that the Incommensuration Theorem entails. I fix the modal alignment used throughout the book in the focus of the two laws (the law of symmetry and the law of continuity): symmetry is omniscient, continuity transcendent and interaction immanent. The immanent, the omniscient and the transcendent are the three modalities, which Section VI describes: the immanent is the mode of process, the omniscient is the mode of structure, and the transcendent is the mode of the generative. I identify the two types of law. I read General Relativity and Quantum Mechanics as the two survivors of the Incommensuration Theorem. Each of the two

theories reaches across the boundary between two modalities, from the one modality into the domain proper to the other modality. I then say what physics is on this account: physics is the study of measurement, and measurement is interaction, bounded above and below and measured by six quantities that answer to the six intrinsics. I close with a guide to the five parts of the collection and to the kind of claim that each part makes.

Note on framework. This introduction is the reference point for the whole volume. Each later essay states its own part of the framework briefly and refers back to this introduction for the full statement. The ground of the framework is set out at length in three foundation volumes: *Comparison; The Necessary Basis*, *Incommensuration; The Theorem and the Three Axioms* and *Measurement; The Steps from Comparison to Physics*. In this introduction I do not presuppose the three foundation volumes, because the argument that I make in this introduction needs only what I state in this introduction.

I. The Root Tautology

Every essay in this book depends on a single identification. The identification is simple enough to be passed over and consequential enough to change how one reads the whole of physics. The identification is that interaction, comparison and relation are one act, named three ways. The three words name one act, seen from three sides.

Consider first what it is to compare. To compare two things is to bring the two things into contact: something must pass between them, some trace of the one thing must reach the other, and some process must connect the two. A comparison can be made only when something crosses the gap between the two things compared. So comparison is interaction.

Consider next the other direction, from interaction to comparison, and ask what it is to interact. When two particles scatter off each other, the outcome is a record of how the two particles were the same and how they

differed. The momenta, charges and spins of the two scattering particles are weighed against one another, and the result of the weighing is expressed in where the two particles go next. So interaction is comparison.

Consider, last, what it is to relate. To stand in a relation to something is to be placed against that thing and compared with it. And to be compared to a thing is to have interacted with the thing. A relation that involves no comparison relates nothing to nothing. So relation is both comparison and interaction.

I call the statement that interaction, comparison and relation are one act the Root Tautology, and I mean the word "tautology" precisely. The Root Tautology is a recognition, and neither a metaphor nor a hypothesis. The recognition is that three vocabularies have been naming one structural act. The vocabulary of physics names the act interaction. The vocabulary of epistemology, the study of knowing, names the act comparison. The vocabulary of mathematics and logic names the act relation. The three names are distinct, inseparable and non-interchangeable: "comparison" names the act as a finding, "interaction" names the act as an event, and "relation" names the act as a standing connection. Interaction, comparison and relation are isomorphic, rather than one thing under a flat identity: they correspond to one another feature for feature. To call an act a comparison describes the act more specifically than to call it an interaction. To call the act an interaction describes it more specifically than to call it a relation. The three descriptions are nested, each inside the next, but the nesting is a nesting of descriptions and not of acts: every act that is one of the three is also the other two. I put a direct challenge to anyone who doubts the Root Tautology: produce an interaction that is not a comparison, a comparison that is not an interaction, or a relation that is neither. The support for the Root Tautology is performative. Anyone who tries to deny the Root Tautology compares the tautology with something else and finds the two different. So the person denying the tautology is already using it in the attempt. The support is also substantive: the six intrinsics, the

four compounds, the Incommensuration Theorem and the three axioms, each of which this introduction sets out below, are all entailed by the Root Tautology.

The Root Tautology has a consequence that gives this book its subject. If interaction and comparison are one, then the intrinsic structure of comparison is the intrinsic structure of physical interaction. Whatever is necessarily true of comparison as such is necessarily true of physics as such. Physics is thereby given its place as the study of interaction, and is not reduced to something other than physics. Interaction has a shape that can be examined before any particular interaction is measured. I lay out that shape in the rest of this introduction.

II. The Six Intrinsics

The concept of comparison has six intrinsics: six features that belong to comparison by its nature. The six intrinsics come in three inseparable pairs: sameness and difference; content and context; the subjective and the objective. Each of the six intrinsics can be defined only with implicit reference to the other five intrinsics.

Content is what is being compared. Context is the frame of the comparison: more exactly, the respect in which the two things compared are two. Sameness is what the compared things share, and difference is how the compared things diverge. The subjective is the perspective from which the comparison is made. The objective is the side about which the comparison is made: the properties of the things compared, independent of who is comparing them.

The count of six is found, not stipulated: one finds that the count is six, and not five or seven, by trying to remove one intrinsic and watching what happens to the act of comparison. A comparison without content compares nothing. A comparison without context has no frame, and so no way to say what counts as same or different. In a comparison without sameness there is no pattern to find, and in a comparison without differ-

ence there is no signal to find. A comparison without the subjective has no standpoint from which it is made. A comparison without the objective has nothing that it is about. Remove any one of the six, and no act of comparison is left. If a seventh intrinsic is proposed, examination shows the seventh to be a compound of the six, such as a relation of sameness across a context or a content held from a standpoint. So all six intrinsics are necessary, and the six together suffice.

The two members of each pair of intrinsics are inseparable in a strong sense. Sameness has meaning only against the possibility of difference, and content has meaning only within some context. The subjective is always the subjective of some objective. Where one member of a pair appears, the other member is present, at least implicitly. The inseparability of the pairs is more than a decorative point. The Incommensuration Theorem, which Section IV states, is proved from the inseparability, and so I ask the reader to keep the inseparability in mind.

The six intrinsics are intrinsic to the act of comparison, and not to the things compared. The act of comparison is an interaction, so the six intrinsics belong to the interaction and so, by the Root Tautology, to the physics. When a later essay says that a physical result is an instance of the structure of comparison, the essay means that the result is a place where the six intrinsics, or their compounds, necessarily show up in the world.

III. The Four Secondary Compounds

The intrinsics can be applied to one another. In particular, the pair sameness and difference can be applied to the pair content and context. There are two choices for the content (same or different) and two choices for the context (same or different), and so there are four compounds.

Continuity is sameness of content within sameness of context. Hold the frame fixed, and the content does not jump. A small shift of context yields at most a small shift of content. Every differential equation requires continuity, and every smooth field is a case of continuity.

Discontinuity is difference of content within sameness of context. Hold the frame fixed, and the content changes anyway: there is a jump or a break, or a threshold is crossed. Examples of discontinuity are the discrete energy levels of an atom, the click of a detector and the difference between one particle and two.

Symmetry is sameness of content across difference of context. Change the frame, and the content is unchanged. Move the apparatus across the room, run the experiment on Tuesday instead of Monday, or rotate the coordinates, and the same law holds and the same conserved quantity keeps its value. Every invariance is a symmetry in the sense of sameness of content across difference of context.

Asymmetry is difference of content across difference of context. Change the frame, and the content changes with the frame. The past differs from the future, here differs from there, and the record of a process differs from the reversal of the process. Every direction, every gradient and every irreversibility is an asymmetry.

I construct the four definitions from the intrinsics of comparison alone, and none of the four is imported from physics or borrowed from mathematics. The construction matters for what follows, because whatever is true of symmetry and continuity by virtue of the four definitions is true wherever comparison occurs. By the Root Tautology, comparison occurs wherever interaction occurs, and interaction occurs everywhere that physics applies.

IV. The Incommensuration Theorem

The Incommensuration Theorem is the central result of the metaphysics as the metaphysics bears on physics. By "the metaphysics" I mean the account of comparison on which this book rests. This section is the place in the book where I state the Incommensuration Theorem in full. The later essays restate the theorem briefly and refer back to this section.

The six intrinsics of comparison are sameness and difference, content and context, and the subjective and the objective. When sameness and difference are applied to content and context, they yield four secondary compounds: continuity, which is sameness of content within sameness of context; discontinuity, which is difference of content within sameness of context; symmetry, which is sameness of content across difference of context; and asymmetry, which is difference of content across difference of context.

There are ten possible pairings of the four compounds. In four of the pairings a compound is paired with itself, and in six of them two distinct compounds are paired. The Incommensuration Theorem says that when any two of the four compounds are applied absolutely and together, two conjunctions are forbidden, symmetry with continuity and asymmetry with discontinuity, while two survive as valid absolute conjunctions, continuity with asymmetry and symmetry with discontinuity.

The qualifier "absolutely applied" is part of the Incommensuration Theorem, and the qualifier is never dropped. To be applied absolutely is to hold exactly, at the foundation of a description. Within any finite domain, symmetry and continuity co-occur, each to some finite degree. A field can be both smooth and invariant to a very high approximation, and most of working physics deals with approximate cases of that kind. Symmetry and continuity cannot both be perfected at once. Under the Incommensuration Theorem, symmetry and continuity may also hold together where their conjunction is mediated, in any of three ways. The conjunction is mediated by level when symmetry and continuity hold of different things: one of the object, and the other of the object's framework. The conjunction is mediated by phase when symmetry and continuity hold at different times in a single procedure, one after the other. The conjunction is mediated by scope when each of the two holds within a bound that the other does not cross. The Incommensuration Theorem says only that symmetry and continuity cannot both be perfected in one description of one thing, which makes the theorem a statement about limits: about what happens when one asks for total symmetry and total continuity in the same description of the same thing.

Why do symmetry with continuity and asymmetry with discontinuity fail, and not the other pairings? Three considerations account for all ten pairings. The first consideration is that self-application is semantically empty: symmetry of symmetry, continuity of continuity, discontinuity of discontinuity and asymmetry of asymmetry say nothing that the single term did not already say. So I set aside the four pairings that are self-applications. The second consideration is that opposites, applied absolutely, are incompatible: total symmetry and total asymmetry, of the same content across the same contexts, are a contradiction, and so are total continuity and total discontinuity. So I set aside two more pairings: the pairing of symmetry and asymmetry, and the pairing of continuity and discontinuity. Four pairings remain, and which of the four survive depends on the third consideration, the inseparability of the intrinsics.

Write out symmetry with continuity, term by term. Symmetry is sameness of content across difference of context, and continuity is sameness of content within sameness of context. When the two are taken together and perfected, the content is the same whether the context changes or does not change. But then the content does not depend on the context at all. And if the content does not depend on the context, the distinction between content and context does no work: the distinction has collapsed. Content and context are two of the six intrinsics, and they are inseparable in the sense that each is defined against the other. If content and context cannot be told apart in a comparison, the comparison is not fully specified. The content and the context cannot be one and the same respect of a comparison. If the respect judged (the content) were the respect that makes the two compared things two (the context), the verdict of the comparison would be fixed before the comparison was made, and a verdict fixed in advance is no verdict. So the act of comparison has undermined itself. Put another way, across the two terms of the conjunction, sameness appears twice on the side of content and difference does not appear at all. Because sameness and difference are inseparable, sameness cannot appear twice where difference appears not at all, when the terms are taken absolutely.

Write out asymmetry with discontinuity in the same way, and the same collapse happens from the other side. Asymmetry is difference of content across difference of context, and discontinuity is difference of content within sameness of context. When the two are perfected together, the content differs whether or not the context differs, so again the content is independent of the context. Again the distinction between content and context collapses, now with difference appearing twice on the side of content and sameness not appearing at all.

The two survivors are the two pairings in which sameness appears once and difference appears once in each respect, content and context: in each survivor, each compound is joined with its exact complement. Continuity with asymmetry joins sameness of content within sameness of context to difference of content across difference of context. In continuity with asymmetry, content and context both appear, and sameness and difference both appear. The content depends on the context, and the dependence is exactly what one would call a continuous process with a direction. Symmetry with discontinuity joins sameness of content across difference of context to difference of content within sameness of context. Again sameness and difference each appear once in each respect. The conjunction of symmetry with discontinuity describes an invariant that comes in discrete units.

The Incommensuration Theorem depends only on what comparison is, and on the inseparability of the intrinsics that comparison requires. The Incommensuration Theorem does not depend on any experiment, on any physical theory or on any particular formalism. So the theorem is not an empirical claim. The Incommensuration Theorem is a structural fact about the nature of knowing. No one can stand outside the theorem to doubt it: to reject the theorem, one must compare the theorem's account of comparison with some other account, and in making the comparison one uses all six intrinsics. So whoever rejects the theorem instantiates the very structure that he or she is rejecting. In this respect the Incommensuration The-

orem has the character of the Cogito of the philosopher René Descartes, the argument that whoever doubts must exist in order to doubt: the act of doubting the theorem enacts the theorem.

I chose the name of the Incommensuration Theorem with care. Symmetry and continuity are incommensurate in the old sense of the word: no common measure exists in which both can be completed together. Each can be increased, and increasing one does not immediately reduce the other. But the two cannot both be brought to completion: the two ideals do not share a summit. The impossibility of completing symmetry and continuity together is the whole of the theorem, and the whole of this book is an examination of the places where physics comes up against that impossibility.

I name here three places where physics comes up against the theorem, each with the book that sets out the argument. The first place is the residue between count and curve. When a count (a number of discrete units) is read by a continuous whole, every such reading leaves a residue, and the residue cannot be zero, because of the Incommensuration Theorem (*The Strengths of the Kinds*, Chapter 5, Section III). The second place is the floor under conjugate descriptions: the lower limit on how sharp two conjugate descriptions can be together. Position and momentum are conjugate descriptions of one state: a state sharply placed in position is spread in momentum, and the reverse, and no description of the state is sharp in both. Physicists call the trade-off between position and momentum the uncertainty principle. *The Quantum Passage* (Chapter 4, Section III) states the uncertainty principle as an instance of the Incommensuration Theorem. The third place is the price of being inside the vacuum. Whoever measures the energy of empty space is inside the vacuum being measured. In *The Gravitational Passage* (Chapter 13) I identify the part of the vacuum's energy that an observer inside the vacuum cannot reach as an instance of the Incommensuration Theorem at the scale of the universe, and I identify the cosmological constant with the part that the observer

can reach. One theorem, then, appears in three places: the residue between count and curve, the floor under conjugate descriptions and the price of being inside the vacuum.

V. The Two Survivors

I pause on the two survivors before going further, because the two survivors recur throughout the book. The two survivors are the two faces that any complete physical description must show.

Continuity with asymmetry is the structure of process. In a process something persists (that is the continuity), and the thing that persists goes somewhere (that is the asymmetry). A wave is the clearest physical image of a process: its phase varies continuously, and no two points along it are identical. Another image of a process is a worldline, the path of a body through space and time, because a worldline is smooth and directed. The differential equation is the native mathematics of process, the mathematics in which process is most directly written.

Symmetry with discontinuity is the structure of the countable. In the countable something is invariant (that is the symmetry), and the invariant thing comes in units (that is the discontinuity). A particle is the clearest physical image of the countable: exchange two of the same kind and nothing changes, yet their number is definite. The native mathematics of the countable is the conserved charge, the quantum number and the eigenvalue (a definite value that a measurement can return).

The Incommensuration Theorem says that at the limit, where a description is pushed to perfection, the description must be one survivor or the other, and that the two survivors cannot be merged into a single perfected description. The Incommensuration Theorem does not say that a physical description must keep one of the two survivors and abandon the other survivor. Within finite domains both survivors are present, in degrees. In the essay on the wave and the particle, later in this volume, I

work out what the presence of both survivors in degrees means for the oldest duality in modern physics: that light and matter show themselves both as waves and as particles.

VI. The Three Axioms

In the order of proof, the Incommensuration Theorem comes first. The theorem is proved from comparison alone: from the six intrinsics, their inseparability and the four compounds. The three axioms are derived from the theorem, as the theorem's internal structure. Here I state only how the three axioms depend on the Incommensuration Theorem, and I define the terms of the three axioms in the paragraphs after this paragraph. In the names of the roles, the Incommensuration Theorem itself is the conjugacy of the omniscient and the transcendent in the first axiom. The conjugacy of the omniscient and the transcendent fixes the direction of the cycle in the second axiom (*Incommensuration; The Theorem and the Three Axioms*, Chapter 8). I set out the three axioms here in the wording of my book *An Immanent Metaphysics*, because I state the modal alignment of the next section, and the account of law after it, in the terms of the axioms. The axioms are statements about the three modalities, the immanent, the omniscient and the transcendent, so I describe the three modalities first.

Where the foundations of any domain can be subsumed by three concepts necessary and sufficient to the domain, those three concepts are its modalities. The *immanent* is the mode of process: of the relational and the interactive, of the here and now, and of what is happening between things. The *omniscient* is the mode of structure: of the repeatable and the shareable, of the third-person, and of what holds regardless of who looks. The *transcendent* is the mode of the generative: of the evaluative, the creative and the potential, and of what makes a domain possible rather than what is found within it. Interaction is immanent, existence is omniscient,

and creation is transcendent. Change is immanent, causality is omniscient, and choice is transcendent. The same pattern recurs at every level, and the way each triple aligns with the three modalities can be checked.

Axiom I. The immanent is more fundamental than the omniscient and/or the transcendent. The omniscient and the transcendent are in conjugate relationship to one another. In plainer words, process is more basic than structure or than possibility. Interaction is prior both to the things that interact and to the space of what the things might become. By the Root Tautology, Axiom I is the same as saying that comparison is prior to what is compared.

Axiom II. A class of the transcendent will precede an instance of the immanent. A class of the immanent will precede an instance of the omniscient. A class of the omniscient will precede an instance of the transcendent. I call the three steps of Axiom II the directed cycle, which runs from the omniscient to the transcendent, then to the immanent, and then back to the omniscient. The direction of the cycle cannot be reversed. A possibility, taken as a kind, gives rise to a particular interaction, interactions taken as a kind give rise to a particular structure, and structures taken as a kind give rise in turn to a particular possibility. Every process in every domain runs through the directed cycle, and the directed cycle is what the word *process* means when used exactly.

Axiom III. The (classes/instances) of the immanent, omniscient, and transcendent are distinct, inseparable, and non-interchangeable. In plainer words, no one of the three modalities can be reduced to the others, each of the three occurs only together with the others, and any substitution of one for another is a mistake. Axiom III states what makes a triple a triple. Axiom III supplies the three tests (distinct, inseparable and non-interchangeable) against which every foundational triple in this book is checked: relation, domain and identity; interaction, existence and creation; choice, change and causality; and reality, existence and objectivity.

The three axioms belong to the domain that they describe. Axiom I is a statement about what holds regardless of position, and so Axiom I has the nature of the omniscient. Axiom II is a statement about process, and so Axiom II has the nature of the immanent. Axiom III is a statement about what makes the three modalities possible at all, and so Axiom III has the nature of the transcendent. Because the axioms fall into the pattern they describe, the metaphysics can ground itself without appeal to anything outside the metaphysics. The fit between the axioms and the pattern is therefore more than a decoration. When the axioms are applied to themselves, they close at the second order of self-description, and the third order adds nothing (*Incommensuration*, Chapter 16).

One further principle is needed before the Incommensuration Theorem can be read exactly. The principle is a consequence of the axioms rather than a fourth axiom. Every domain is *zero-positive*: the fundamental measures of the domain have an absolute minimum but no absolute maximum. Zero-positivity is a statement about the measures of a domain, and zero-positivity is not the ground of the theorem's qualifier. The qualifier "absolutely applied" means holding exactly, at the foundation of a description. In every real system, symmetry and continuity appear together approximately, and most of working physics deals with that approximate joint appearance. Under the Incommensuration Theorem, symmetry and continuity cannot both hold exactly in what is found by one and the same comparison, and likewise asymmetry and discontinuity cannot both hold exactly there. The two survivors can hold exactly, while the two forbidden conjunctions cannot. In *Unlocking Reality*, my companion essay on zero positive sets out the principle of the floor. The principle of the floor is the principle that every fundamental measure has an absolute minimum.

I give the derivation of the axioms from the Incommensuration Theorem in full in *Incommensuration*, whose Chapter 8 sets out every step in one table. The three axioms are three facets of a single structural result, the Incommensuration Theorem, so the ground of the framework is a theorem alone, not axioms plus a theorem.

VII. The Two Types of Law

Where there is a concept of lawfulness, the instances of lawfulness are of only two basic types: any law is either a law of symmetry or a law of continuity, and there is no third type. Every law ever formulated in any field is a law of symmetry, a law of continuity or a compound of the two.

A law of symmetry is a law of invariance: sameness of content across difference of context. Conservation of energy is a symmetry law. Another symmetry law is the physicist Isaac Newton's third law of motion: every force one body exerts on another is matched by an equal and opposite force. A symmetry law about laws is the statement that the laws of physics are the same in every inertial frame, which is every frame of reference moving at a steady speed in a straight line. A law of continuity is a law of persistence: sameness of content within sameness of context. Physicists assume that the state of a body changes smoothly with the forces upon the body, and that assumption is a continuity assumption of physics. Continuity governs the arena in which the state of the body changes: space and time. An experiential stream admits no absolute gaps, and the law that says so is a continuity law.

I use "the focus of the two laws" to mean the framing in which the two types of law are what is in view, and in that focus the metaphysics makes a definite assignment of modalities, which I fix for the whole of this book. Where the book uses other assignments of modalities later, each assignment names its own focus where it is made. In the focus of the two laws, symmetry has the nature of the omniscient modality, continuity has the nature of the transcendent modality, and interaction has the nature of the immanent modality.

The reasons for the assignment come from what each modality is. The omniscient is the mode of the domain and of what holds throughout: the same content across every context, which is symmetry. The omniscient is also the mode of the object, of existence and of what is known. The tran-

scendent is the mode of identity and of the singular that persists as itself: the same content within its own context, which is continuity. The transcendent is also the mode of the subject and of what is understood. The transcendent is the mode of objectivity in the strict sense: the standpoint that is not any particular standpoint. The immanent is the mode of relation: the interaction where knowing and understanding both occur, and the reality where object and subject meet. Accordingly, laws have the nature of the omniscient, principles have the nature of the transcendent, and axioms have the nature of the immanent.

So symmetry governs world, continuity governs self, and physics is done in the interaction between world and self. The essay on the two types of law opens Part I, and there I work out what the assignment means for conservation, quantization and uniqueness. Here I draw only the one consequence of the assignment on which the rest of the book is organized.

The Incommensuration Theorem says that symmetry and continuity cannot both be perfected together. The assignment of modalities says that symmetry is the tool proper to the omniscient and that continuity is the tool proper to the transcendent. Three paragraphs below, I say exactly what I mean by a theory's tool. Now consider the two great theories of twentieth-century physics, General Relativity and Quantum Mechanics.

General Relativity is continuity with asymmetry. In General Relativity, what is found is a smooth continuum of events, and the formalism in which the continuum is written is invariant under every smooth change of coordinates, which is a symmetry of the description. The characteristic results of General Relativity are directed: lightcones (the bounds of what a signal from an event can reach), horizons and the irreversible collapse. General Relativity is the first survivor of the Incommensuration Theorem, the pairing of continuity with asymmetry. Continuity is the tool proper to the transcendent. But General Relativity is applied to the macroscopic, to the cosmos, to the whole, and the macroscopic is the omniscient domain.

Quantum Mechanics is symmetry with discontinuity. In Quantum Mechanics, what is found is invariant (the conserved quantum numbers, the charges and the exchange symmetry of identical particles), while the unitary group, the continuous group of transformations of the quantum state, acts in the continuous formalism of Quantum Mechanics. The characteristic results of Quantum Mechanics are discrete: the quantum, the eigenvalue, the click. Quantum Mechanics is the second survivor of the Incommensuration Theorem, the pairing of symmetry with discontinuity. Symmetry is the tool proper to the omniscient. But Quantum Mechanics is applied to the microscopic, to the singular event, to what is only itself, and the microscopic is the transcendent domain.

In both General Relativity and Quantum Mechanics, then, physicists apply the tool proper to one of the two modalities, the omniscient and the transcendent, to the domain proper to the other of the two modalities. I call the crossing of each theory into the domain of the other modality the cross-modal reach. I want to be clear that the crossing is required, not accidental. By a theory's tool I mean the character, continuity or symmetry, that is perfected in the theory's findings, while the theory's other character is carried exactly, at the other level, in the theory's formalism. The cross-modal reach is dense but never exhaustive: each theory applies as closely as one likes to every part of the other domain, and never to the whole of the domain (*Measurement*, Chapter 8). A tool applied to its own domain adds nothing to what the domain already gives, because self-application is semantically empty, which is the first of the three considerations in Section IV. To learn anything about the omniscient, one must reach into the omniscient with the transcendent's tool, and to learn anything about the transcendent, one must reach into the transcendent with the omniscient's tool. Only by crossing into the domain proper to the other modality, the modality whose tool the theory does not use, could either General Relativity or Quantum Mechanics have been a theory at all. So the crossing is not a defect awaiting repair. In the essay on cross-modal reach, in Part III, I argue from the required crossing that no single theory can unify General Relativity and Quantum Mechanics in the strong sense.

In a theory of which both are limits, both survivors would have to be found perfected at once, in what is found by one and the same comparison, and the Incommensuration Theorem says that exactly this perfection of both survivors at once is impossible.

VIII. What Physics Is, on This Account

It remains to say what physics is on this account, so that the reader knows what kind of object the essays are examining.

Physics is the study of measurement, and measurement is interaction under a particular description. In *An Immanent Metaphysics* I put the point as an isomorphism: the concept of a measurement is isomorphic with the concept of an observation, a perception, and an interaction. If anything is epistemically true of one of the four concepts, measurement, observation, perception and interaction (true of that concept as a way of coming to know), then the same thing is true of the other three concepts. The isomorphism is the Root Tautology brought to bear on the practice of physics. The isomorphism has a consequence that I regard as decisive for the boundaries of the discipline: whoever claims, in physics, to describe something beyond all possible measurement has stopped doing physics. Nor has that person thereby started doing metaphysics, because metaphysics is the study of the structure of comparison that physics already is, and only what could be reached by some comparison can be the basis of an assertion, in physics or out of it. I develop the claim that measurement is interaction in the essay on measurement as interaction, in Part I. I follow that claim out to the edges of physics in the essays of Part IV.

Because measurement is interaction, the six intrinsics of comparison have a physical face. In *An Immanent Metaphysics* I name six measures, mass, space, force, time, probability and possibility, and on this account the six measures are what the six intrinsics look like when the comparison is a physical one. I do not develop the correspondence between the six measures and the six intrinsics here. I argue the correspondence member

by member in *Comparison; The Necessary Basis*, where I also derive the count, six, as three roles taken twice, once as content and once as context (Chapter 8, and Chapter 5, Section VIII). In the essay on the six measures and the six intrinsics, in Part I of this volume, I build on that argument.

Physics has boundaries, because measurement is interaction, interaction is comparison, and comparison has a domain. Physics has two boundaries, and both boundaries are constants that every physicist knows, while the knowing self has a third boundary, the mesoscopic (the scale between the smallest and the largest), which carries no constant (Essay 14). The microscopic limit is marked by Planck's constant. Below the amount of action that Planck's constant marks, no measurement distinguishes jointly what a pair of conjugate quantities would need to fix. Position and momentum are a pair of conjugate quantities. When something crosses the microscopic boundary into the domain of comparison, it can appear only as what we call random. The macroscopic limit is marked by the speed of light. No signal can arrive from beyond the boundary that the speed of light marks. Whatever lies past the macroscopic boundary is structurally unreachable, not merely slow to reach us. On this account each constant is first of all an edge of the domain of comparison, and not a speed or a size. Planck's constant is the edge at the smallest distinguishable difference, and the speed of light is the edge at the farthest possible connection. Between the two edges, Planck's constant and the speed of light, lies everything that can be measured, which is to say everything that is physics. I develop both boundaries in the essays of Part IV. I develop the macroscopic boundary in particular in the essay on causation and connectivity, in Part III.

And because comparison has two survivors and two forbidden conjunctions, physics has a definite shape at its limits. Where physicists ask for perfect symmetry, they will find discontinuity, and that discontinuity is quantization. Where physicists ask for perfect continuity, they will find asymmetry, and that asymmetry is the arrow of time. Where physicists ask for perfect symmetry and perfect continuity at once, they will find that they cannot have both. The impossibility of having both shows up as

three failures: the failure of determinism, the failure of unification, and the failure of any hidden variable to restore what Bell's theorem took away. Determinism is the view that the state of the world at one time fixes its state at every later time, and a hidden variable is a quantity, beyond those of quantum mechanics, that would fix each outcome in advance. The physicist John Bell proved Bell's theorem, which shows that no theory of local hidden variables can reproduce every prediction of quantum mechanics. The subjects of the essays are quantization, the arrow of time and the three failures (of determinism, of unification, and of any hidden variable to restore what Bell's theorem took away).

The axioms and the modalities are closed and self-consistent under reason, both in process and in theory, in several overlapping and intersecting ways. The axioms and the modalities also close completely over the basic notions of comparison, description, process and interaction. In physics interaction is named "particle", and the same basic notions appear as intersection, field and measurement, so all of these words are different words for the same patterns. Within the scope of the axioms and the modalities, their terms and their process, lie all of mathematics, computer science and physics, and all of reason and argument itself. Everything that the account needs lies within the axioms and the modalities. The structure of the arguments is fully deterministic and exact, and every definite thing follows from that structure. What is not determined is not determined at all, so randomness, where it appears, is hard randomness: randomness determined in no way whatever. In the essay on hard randomness, in Part II, I say why.

The Standard Model as Inherited Code

Every experienced software engineer has encountered a legacy system: a large, complex codebase (a body of program code) that has been written and rewritten over decades, by many hands, with inconsistent conventions, incomplete documentation, and no single architect who understands the whole. A legacy system works, in that the system produces cor-

rect outputs for known inputs, but no one can explain why the system works, and anyone who tries to modify the system risks breaking something that is relied upon but not understood.

The Standard Model of particle physics is the theory of the known particles and of every known force except gravitation. The Standard Model is a legacy system. Thousands of contributors have constructed the Standard Model over more than fifty years, using multiple formalisms: Lagrangian field theory, path integrals, lattice methods and effective field theory. The parameters of the Standard Model are measured rather than derived, and the Standard Model has internal tensions (the hierarchy problem, the strong CP problem, the cosmological constant problem) that everyone acknowledges but no one has resolved. The Standard Model produces correct outputs. The predictions of the Standard Model have been confirmed to extraordinary precision, and in the case of the magnetic moment of the electron (the strength of the electron's own magnetism), to about one part in a trillion (Fan, Myers, Sukra and Gabrielse, 2023). By any operational measure, the Standard Model is the most successful scientific theory ever constructed. And the Standard Model is a mess.

When an engineer confronts a legacy system, the first task is to sort the codebase into categories, because the things in the repository (the store that holds the system's files) are of different kinds. Some of the repository is executable code and some is configuration, some is test output and some is commentary. The first and most common error in sorting a legacy codebase is to treat the different kinds of thing in the repository as interchangeable.

Category A is the action machinery, the code that runs, and in the Standard Model the action machinery is the Lagrangian density, the path integral formulation, the Feynman rules and the renormalization group equations. The action machinery is the computational apparatus that transforms inputs (initial states, momenta and quantum numbers) into outputs (cross-sections, decay rates and spectra). Category A is the transform engine.

Category B is the configuration: the selectable inputs, which are the plug-in modules, the library choices, and the parameters that configure the transform engine for a specific run. In the Standard Model, the configuration includes the choice of gauge group ($SU(3) \times SU(2) \times U(1)$), the fermion representations (three generations of quarks and leptons), the structure of the Higgs sector, and the free parameters (coupling constants, masses, mixing angles, CP-violating phases). There are nineteen free parameters with massless neutrinos, and twenty-six once each neutrino carries a Dirac mass, which adds three masses, three mixing angles and one phase (*The Branches of the Kinds*, Chapter 1). Category B is what you plug in before you press "run".

Category C is the outputs: the computed results, which are the predictions that the Standard Model produces when it is configured and executed. The outputs include cross-sections for specific scattering processes, branching ratios for particle decays, mass spectra, mixing angles and CP asymmetries. Category C is what you check against experiment.

Category D is the documentation: the interpretive material that surrounds the code. In the Standard Model, the documentation is the symmetry principles, the naturalness arguments, the hierarchy problem, the development roadmaps (grand unification, supersymmetry, string theory), and the conceptual frameworks (gauge invariance, spontaneous symmetry breaking, the Higgs mechanism). Category D is orientation material, which says what the system is supposed to be doing. But in a legacy codebase the documentation is often outdated, incomplete or simply wrong.

> **On the Separation of Categories**
>
> The main lesson of the legacy-system analogy is that the four categories of the codebase, A to D, must be treated separately and in the right order. For the Standard Model, the commonest error is to start from the outputs (C) and work backwards, or to take the documentation (D) at face value. Both approaches fail, because the outputs are meaningful only when the transform engine (A) and the configuration (B) are understood, and the

> documentation may or may not describe what the code actually does. The correct order of engagement is to understand A (the machinery), then B (the configuration), then the A+B combination as a fixed transform, and only then do the outputs (C) become interpretable. The documentation (D) should be consulted for orientation but trusted for nothing.

An engineer who encounters a legacy codebase should work in a correct order of operations, which has four steps. First, examine the documentation (D) for general orientation, and note what the system is supposed to do. Then set the documentation aside, and trust nothing in the documentation until the code confirms it. Second, identify the canonical configuration (B): find out what modules are loaded, what parameters are set and what libraries are linked, and isolate the set of inputs that define the system's operating state. Third, trace the action machinery (A): read the code, understand the transforms, and see how the inputs of B flow through the machinery of A to produce the outputs of C. Fourth, and only fourth, examine the outputs (C), which become interpretable now that A and B are understood. A discrepancy between a predicted output and an observed output can then be diagnosed, by asking whether the error is in A (the machinery), in B (the configuration), or in the observation.

In this account I approach the Standard Model in exactly the same four-step order. I consult the documentation of the Standard Model (naturalness, hierarchy arguments and grand unification narratives) for orientation, but I trust the documentation for nothing. I identify the configuration of the Standard Model (gauge groups, generations, masses) and analyze its structure in *The Kinds of Particle*, *The Strengths of the Kinds* and *The Measures of the Kinds*. I examine the machinery of the Standard Model (the Lagrangian structure, the path integral and the renormalization group) for compliance with the account's structural constraints. And the outputs of the Standard Model (the predictions) become interpretable only after the machinery and the configuration are both understood.

In a well-designed system, the boundary between code and data is sharp. The program is fixed, and the data varies. The program transforms the data, and the data does not modify the program. Computer designers call a clean separation between instruction and operand (the program and the data that the program acts on) the Harvard Architecture. In the Standard Model the boundary between code and data is permeable: many quantities appear to be "parameters" (category B) but are actually computed intermediate values, outputs of upstream transforms that feed as inputs into downstream transforms. The coupling constants "run" with energy scale: their values at one energy are computed from their values at another energy through the renormalization group equations. Physicists compute the masses of composite particles (protons and neutrons) from the underlying dynamics of quantum chromodynamics, the theory of the strong force that binds quarks. The effective potential of the Higgs field is computed from loop corrections that involve all the other parameters of the Standard Model.

The Standard Model is closer to a self-modifying program, or to an interpreter framework in which even the language specification is variable, than to a Harvard Architecture. The boundary between "what the program is" and "what the program acts upon" shifts with the energy scale, the approximation scheme and the level of description. The permeability of the boundary is why the Standard Model is hard to refactor, that is, hard to restructure while keeping what it computes. You cannot isolate the code from the data, because the code generates some of the data that it then consumes. To pin down a fixed set of "true inputs", one must choose an energy scale, an approximation scheme and a level of description, and all three choices are themselves conventions rather than facts.

The account is to the Standard Model what hardware is to software. Many different programs can run on the same hardware, so the hardware does not specify the software. But the software must comply with the hardware's constraints: every program must satisfy the instruction set, the memory architecture and the timing constraints of the platform it runs on.

In the analogy, the account specifies the hardware. The three axioms are the instruction set, the six intrinsics are the register file, and the Incommensuration Theorem is the timing constraint. The domain structure is the memory architecture: the microscopic limit at Planck's constant, the macroscopic limit at the speed of light, and the mesoscopic limit at the act of comparison itself, which carries no constant of physics (*Measurement; The Steps from Comparison to Physics*, Chapter 7, Section IV). The Standard Model is the software, and the Standard Model runs on the hardware that the account specifies, so the Standard Model must comply with the axioms, the intrinsics, the theorem and the domain structure. In the specific implementation, whatever the constraints leave open is the software's business, not the hardware's, and how much the constraints leave open is a question that I answer item by item in the books on the kinds of particle. The gauge group, for example, is derived from the constraints (*The Kinds of Particle*, Chapters 3 to 5), and so the gauge group is a hardware question, not a software choice.

The hardware and software analogy clears up a persistent confusion about what the account is. The account is not a theory that competes with the Standard Model. In the account I propose no different forces and no different equations. The particles that the account states are the measured ones, with each neutrino carrying a right-handed partner and a Dirac mass (*The Kinds of Particle*, Chapter 6, Section I; *The Branches of the Kinds*, Chapter 1). In the account I identify the structural constraints that any correct theory of particles and forces must satisfy. In the books on the kinds of particle I argue that the Standard Model satisfies those constraints. So the account states why the Standard Model has the structure it has, and the Standard Model states what the specific content is.

> **On the Map, the Compass, and the Position**
>
> A traveler finding the way through unknown terrain uses three tools: a map, a compass and a knowledge of position. The map is the structural overview of the territory. The compass is the instrument that determines direction relative to an external reference. The knowledge of position is

> the traveler's own location within the terrain, found by an actual sighting. The three tools form a triple. The map is omniscient-modal: a complete and external structural representation, laid out and held in view as a whole. The compass is transcendent-modal: it is the standard against which every bearing is read, and it points to something beyond the traveler's immediate context. The position is immanent-modal: the actual here-and-now of the traveler's engagement with the terrain. In the relation between the account and the Standard Model, the Standard Model, as a theory, provides the map, because in every framing of theory and practice, theory is the omniscient (*Incommensuration; The Theorem and the Three Axioms*, Chapter 12, Section I). The measurements provide the position, because each finding is an act, here and now. The account provides the compass: the frame that relates the theory to its findings, which is the transcendent in the framing where the practice is in focus (the same section). A map without a position is an abstraction that cannot be applied. A position without a map is an experience that cannot be understood. The compass is what allows the traveler to bring the map and the position into alignment. In the same way, the account is what allows the Standard Model and the measurements to be brought into alignment.

A process of computation can be seen at three levels: the running program, the refactoring that turns one program into another while keeping what it computes, and the design of the language in which any such program is written (*Comparison; The Necessary Basis*, Chapter 7, Section VI). Working at the third level has one deepest consequence: one can define what "sorted" means. At the first level, the Standard Model is a sort algorithm, a procedure that puts things in order: the inputs of the Standard Model are unsorted (initial states), and its outputs are sorted (final states arranged by probability amplitude). Different formalisms (Feynman diagrams, path integrals, lattice methods) are different sort algorithms, which produce the same sorted order by different procedures.

At the second level, the refactoring question is whether the different procedures are really computing the same thing. The refactoring question is the question of equivalence. One question of equivalence is whether the

path integral reproduces the canonical quantization. Another question of equivalence is whether lattice quantum chromodynamics reproduces perturbative quantum chromodynamics in the appropriate limit. Processes at the second level transform one sort algorithm into another while preserving the sorted order.

At the third level, the questions are what constraints any sort algorithm must satisfy, what it means for the outputs to be "correctly sorted", and what structural invariants any valid computation must preserve. The account that I give in this book is an answer to the questions of the third level, the level of the design of the language in which any program is written. The three axioms fix what "correctly sorted" means for any representation of the physical world. The six intrinsics of comparison fix the categories that any valid computation must preserve. The Incommensuration Theorem holds of every comparison, and so the theorem sets the trade-off between symmetry and continuity that the findings of any theory must respect: symmetry and continuity cannot both be perfected in the findings of a single theory. The three axioms, the six intrinsics and the Incommensuration Theorem are properties of sortedness itself, and not properties of any particular sort algorithm.

IX. How to Read This Collection

The collection is in five parts, and each part contains a different kind of claim. I want the reader to know in advance which kind of claim is made where, because I state each claim at its true strength, and a claim keeps that strength only while the difference between the kinds is kept.

The claims of the book are of three kinds. Claims of the first kind are claims of the metaphysics itself: the six intrinsics, the four compounds, the Incommensuration Theorem, the three axioms, the two types of law, and the six measures. Claims of the first kind are the ground of the book, and I argue them from the structure of comparison and from nothing else.

Claims of the second kind are readings of known physics. In a reading I take a result that physics has already established, by its own methods and on its own evidence, as an instance of the structure of comparison, and the claim made is that the structure of comparison is the reason the result is true. The results read in this way include Noether's theorem (the proof, by the mathematician Emmy Noether, that every continuous symmetry of a physical law comes with a conserved quantity), Bell's theorem, the uncertainty relations, the wave and the particle, and the quantum character of the microscopic. The essays do not re-establish the results: the essays say what, on this account, each result is an instance of.

Claims of the third kind go past interpretation to qualitative structural exclusion. In this book I make five structural exclusions. The first two structural exclusions are the claims that no world is perfectly deterministic and that superdeterminism is a category error. The third and fourth structural exclusions are the claims that no signal crosses the macroscopic boundary and that there is an arrow of time prior to the thermodynamic arrow of time. The fifth structural exclusion is the claim that no single theory can have both survivors, that of General Relativity and that of Quantum Mechanics, perfected at once in the findings of that single theory. Superdeterminism is the view that the experimenters' choices were fixed in advance, together with what the particles do. Structural exclusions are consequences of a particular kind: they say what physicists will not find, and they say it structurally, not numerically. I derive no number in this book, and where a number appears, the number is quoted from the physics literature, and I say so in the essay where the number appears. My program of research makes derivations of physics from comparison, and I set out those derivations in other volumes.

In Part I, The Two Laws, I lay the ground: symmetry and continuity as the two types of law, determinism as the forbidden conjunction, measurement as interaction, and the six measures. The claims of Part I are of the first two kinds, except for the exclusion of perfect determinism, which is of the third kind.

Part II, Known Results as Instances, is reading throughout: the readings of Bell's theorem, of hard randomness, of the question of the deep why, and of the wave and the particle. In Part II every result is located within the structure of comparison, and no result is re-established.

In Part III, Structural Exclusions, I say what cannot be: superdeterminism, faster-than-light signaling, a time-symmetric world, and a single theory in whose findings both survivors are perfected, and Part III closes with the three kinds of acceleration, as a partition that the metaphysics requires.

In Part IV, The Boundaries of Physics, I follow the domain of comparison to its edges: the three horizons, the domain constants, the microscopic boundary, and what physics cannot reach at all. The claims of Part IV are the metaphysics applied to itself. In the essay on domain constants I present correspondences and argue for no value.

In Part V, Computation and the Continuum, I apply the same instruments (the intrinsics, the Incommensuration Theorem and the axioms) to the question of whether a world could be computed: the continuum argument against simulation and the argument against computationalism.

Every essay ends with a Summary, which says what the essay really is and opens with a statement of the kind of claim the essay makes. A framework like this one is most often misunderstood by being credited with more than it says or less, rather than by being rejected. The statement of the kind of claim is there to prevent both misunderstandings.

This volume rests on the three foundation volumes, *Comparison; The Necessary Basis*, *Incommensuration; The Theorem and the Three Axioms*, and *Measurement; The Steps from Comparison to Physics*, and the volume is a companion to the earlier volumes of the framework, *Third Resolutions in Western Philosophy*, *Unlocking Reality*, *Accessing the Real*, and *The Structure of Effective Choice*. I refer to those volumes by title where I build on them, and I do not restate what they contain. This introduction supplies whatever a reader who has not read those volumes would lose.

X. Summary

In this introduction I state a framework and the framework's vocabulary. The central claims of this introduction are claims of the metaphysics itself: the six intrinsics, the four compounds, the Incommensuration Theorem, the axioms that the theorem entails, the two types of law, and the modal alignment in the focus of the two laws. I read General Relativity and Quantum Mechanics as the two survivors, and the two constants (Planck's constant and the speed of light) as boundaries of comparison. Both readings are readings of known physics as an instance of the structure of comparison. The exclusions in this introduction are consequences of the structure of comparison for physics. I argue each exclusion in the essay devoted to it.

Physics is the study of interaction, interaction is comparison, and comparison has a structure that was there before any measurement was made. The structure of comparison is six intrinsics in three inseparable pairs, four compounds built from the intrinsics, and one theorem about which of the compounds can be perfected together. Symmetry with continuity cannot be perfected together. Asymmetry with discontinuity cannot be perfected together. Continuity with asymmetry can be perfected together, and General Relativity is what that conjunction looks like. Symmetry with discontinuity can be perfected together, and Quantum Mechanics is what that conjunction looks like. In each theory the tool of one modality is applied to the domain of the other, and each theory had to be built that way.

The structure of comparison yields a way of reading physics that does not compete with physics. The reading says nothing about what the physicist should measure or what a measurement will yield, but the reading says where the measurements will run out, and why, and what shape the discipline must have at the places where the measurements run out. Physicists have been finding those places for a century, one at a time, and each place came as a surprise. The essays in this book are an attempt to say that

the places were not surprises, and that the places are the boundary of comparison, seen from inside. The essays are also an attempt to say that a physics built in the knowledge that the places are the boundary of comparison loses nothing, and gains its own outline: the shape of the boundary within which physics is done.

KEY CONCEPTS IN THIS ESSAY

- **Root Tautology**: interaction, comparison and relation are one act, named three ways; read as a formal triple, each is the other two seen from one side, and every description is nested within the comparison it describes.
- **Six intrinsics**: sameness and difference, content and context, the subjective and the objective; three inseparable pairs, necessary and sufficient for any comparison.
- **Continuity**: sameness of content within sameness of context; the structure of persistence and smooth variation.
- **Discontinuity**: difference of content within sameness of context; the structure of the jump, the threshold, the discrete unit.
- **Symmetry**: sameness of content across difference of context; the structure of invariance and conservation.
- **Asymmetry**: difference of content across difference of context; the structure of direction and irreversibility.
- **Incommensuration Theorem**: of the ten pairings of the four compounds, applied absolutely and together, symmetry with continuity and asymmetry with discontinuity are forbidden; continuity with asymmetry and symmetry with discontinuity survive; within any finite domain all four co-occur to finite degree.
- **Absolutely applied**: the qualifier in the theorem; a compound applied absolutely holds exactly at the foundation of a description, without mediation by level, phase or scope; the claim concerns that exactness, not co-occurrence in finite degree.

- **Three axioms**: derived from the theorem (*Incommensuration*, Chapter 8), in the wording of *An Immanent Metaphysics*, aphorism 1.3-1. Axiom I. "The immanent is more fundamental than the omniscient and/or the transcendent. The omniscient and the transcendent are in conjugate relationship to one another". Axiom II. "A class of the transcendent will precede an instance of the immanent. A class of the immanent will precede an instance of the omniscient. A class of the omniscient will precede an instance of the transcendent". Axiom III. "The (classes/instances) of the immanent, omniscient, and transcendent are distinct, inseparable, and non-interchangeable". Zero-positivity is a consequence of the axioms, not a fourth axiom.
- **Modal alignment**: in the focus of the two laws, symmetry omniscient, continuity transcendent, interaction immanent; object omniscient, subject transcendent; laws omniscient, principles transcendent, axioms immanent; other bindings name their own focus.
- **Two types of law**: every law is a law of symmetry or a law of continuity; symmetry governs world, continuity governs self.
- **Cross-modal reach**: General Relativity applies the transcendent's tool (continuity with asymmetry) to the omniscient domain (the macroscopic); Quantum Mechanics applies the omniscient's tool (symmetry with discontinuity) to the transcendent domain (the microscopic); a theory's tool is the character it perfects in what it finds, the other character being carried exactly in its formalism; the crossing is required because self-application is empty.
- **Measurement as interaction**: measurement is interaction read through two descriptions; a physics claiming to reach beyond all possible measurement has stopped doing physics, and has not thereby started doing metaphysics, which is the study of the structure of comparison that physics already is.
- **Six measures**: mass, space, force, time, probability, possibility; three roles taken twice, as content and as context; the physical face of the six intrinsics (*Comparison*, Chapter 8).

- **Two boundaries**: Planck's constant as the microscopic edge of the domain of comparison and the speed of light as the macroscopic edge; each a limit of measurement before it is a size or a speed.

Materials Reviewed

Landry, Forrest. *Comparison; The Necessary Basis.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-062-6.

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3.

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0.

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.43-6 (measurement, observation, perception, interaction); 1.45-1, 1.45-5, 1.45-8 (relation, domain, identity); 1.53-6 (axioms, laws, principles); 1.83-1 to 1.83-5 (the universal law); 1.85-3 (the six intrinsics of interaction); 1.85-8 (the six measures).

Landry, Forrest. *Third Resolutions in Western Philosophy.* Wytheville, Virginia: UVSM Publications.

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapter on the universal law.

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six measures.

Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Landry, Forrest. *The Kinds of Particle.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-060-2. Chapters 3 to 5 (the gauge group derived); Chapter 6, Section I (the neutrinos).

Landry, Forrest. *The Strengths of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-115-9. Chapter 5, Section III (the residue between count and curve).

Landry, Forrest. *The Measures of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-116-6.

Landry, Forrest. *The Branches of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-077-0. Chapter 1 (the free parameters; the Dirac masses of the neutrinos).

Landry, Forrest. *The Quantum Passage; Quantum Mechanics from the Structure of Comparison.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-073-2. Chapter 4, Section III (the uncertainty principle as an instance of the theorem).

Landry, Forrest. *The Gravitational Passage; Deriving General Relativity from the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-056-5. Chapter 13 (the vacuum and the cosmological constant).

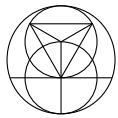
Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Fan, X., T. G. Myers, B. A. D. Sukra, and G. Gabrielse. "Measurement of the Electron Magnetic Moment." *Physical Review Letters* 130 (2023): 071801.

Noether, Emmy. "Invariante Variationsprobleme." *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen* (1918): 235–257.

PART I

The Two Laws



Essay 1

Symmetry and Continuity as the Two Types of Law

On Conservation, Quantization, and Uniqueness

ABSTRACT

Every law is a law of symmetry or a law of continuity. There is no third type. Symmetry governs world and has the nature of the omniscient, the mode of what holds throughout, the same content across every context. Continuity governs self and has the nature of the transcendent, the mode of the singular that persists as itself. Interaction has the nature of the immanent, the mode of relation, and interaction is where world and self meet. In this essay I take that assignment of symmetry to world and continuity to self, and I follow the assignment to three consequences. The first consequence is that conservation is a structural feature of any domain governed by symmetry, so that I read Noether's theorem, which pairs each continuous symmetry with a conserved quantity, as the formal instance of a necessity that precedes any particular Lagrangian (the one function from which a physicist derives the equations of motion of a system). The second consequence is that the Incommensuration Theorem requires the content of a symmetric domain to be discontinuous at the limit, where the symmetry is perfected. So quantization is the shadow of symmetry: what perfected invariance must look like, and not something peculiar to this world. The third consequence is that the Incommensuration Theorem also requires the context of a continuous domain to be

asymmetric at the limit, where the continuity is perfected. So uniqueness is the shadow of continuity. The reason is that a perfectly symmetric self, identical to another self and yet persistent, would be the forbidden conjunction itself: symmetry with continuity, perfected together in one thing. I close the essay by noting that no conservation law can hold perfectly across all conditions, and by saying what kind of claim each of the essay's results is.

Note on framework. This essay depends on the Introduction to this volume. The Introduction states the six intrinsics (sameness and difference, content and context, the subjective and the objective), the four secondary compounds (continuity, discontinuity, symmetry and asymmetry), the Incommensuration Theorem in full, and the modal alignment used throughout. In this essay I build on the chapter on the universal law in my book *Unlocking Reality*, and I do not restate that chapter. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Two Types of Law

Where there is a concept of lawfulness, taken as a class, the instances of that class will be of only two basic types. Any instance of a law will be either a law of symmetry or a law of continuity.

A law of symmetry is a law of invariance, and an invariance is something that stays the same when something else is changed. The content of a comparison is what is being compared, and the context is the frame within which the comparison is made. Symmetry is sameness of content across difference of context, in the terms fixed in the Introduction. Conservation of energy is a symmetry law, because the total energy (the content) is the same across different times and configurations (the context). Newton's third law is a symmetry law: the force is the same under exchange of agent and patient. The agent is the body that pushes, and the patient is

the body that is pushed. The principle of relativity is a symmetry law about laws themselves: the same lawfulness holds in every inertial frame, that is, for every observer moving at a steady speed in a straight line.

A law of continuity is a law of persistence. Continuity is sameness of content within sameness of context. One continuity law is that a trajectory, the path of a moving body, does not jump from one place to another. Another continuity law is that the self who wakes is the self who slept. A third continuity law is that an experiential stream admits no absolute gap within a single experience.

The two types of law, symmetry and continuity, are exhaustive. Every law is of one type or the other. I have argued for the exhaustiveness in *Unlocking Reality*. I will not repeat the argument for exhaustiveness in this essay, except to say where the argument comes from. The four secondary compounds of comparison are continuity, discontinuity, symmetry, and asymmetry. Each compound applies sameness or difference to content, and sameness or difference to context. A law is a statement of what stays the same, and two of the four compounds are statements of sameness of content: symmetry and continuity. The statements of what changes are discontinuity (difference of content within sameness of context) and asymmetry (difference of content across difference of context), and a law about what changes is, on examination, a law about what stays the same under that change. There is no third sameness to be a law of.

II. The Assignment

The metaphysics on which this book rests makes a definite assignment of the two types of law, and the whole of this volume uses that assignment.

The basic beingness, nature, and lawfulness of all world is defined by, and founded upon, symmetry. The basic beingness, nature, and lawfulness of all self is defined by, and founded upon, continuity.

World is what lies outside the boundary of self: world is objective in the ordinary sense, and world has the nature of existence. World has also the nature of the omniscient modality, the mode of what holds throughout. The lawfulness of world is a lawfulness of content: the same content across every context, the same law everywhere. Symmetry is omniscient.

Self is what lies inside the boundary of self: self is subjective, and self has the nature of creation. Self has also the nature of the transcendent modality, the mode of the singular that persists as itself. The lawfulness of self is a lawfulness of context: the frame that persists as itself, the standpoint that is not exchanged for another. Continuity is transcendent.

World and self meet in interaction: in interaction, world is perceived by self, and self is expressed into world. The interaction of world and self has the nature of the immanent modality, the mode of relation. Interaction is immanent. Interaction is where measurement happens, and so interaction is where physics happens.

I call this assignment (symmetry to world, continuity to self, and interaction between world and self) the universal law. The universal law is the structural principle that says what kind of law governs each aspect of reality. The universal law is not a particular law within a particular domain. Physics is the study of world, so the content that physicists find falls under symmetry law, and the arena in which physicists find that content, space and time, falls under continuity law. Psychology is the study of self. Continuity governs self, so psychology is a system of continuity laws. The laws of physics and of psychology are not in competition, because the two sets of laws are laws of different things, world and self. The Incommensuration Theorem says that the two types of law could not have been laws of the same thing, perfected together.

III. The Four Theorems of Being

Four propositions follow from the universal law and the Incommensuration Theorem together, and I call the four propositions the four theorems of being. The four propositions organize everything in the rest of this essay. The Introduction states the Incommensuration Theorem in full: symmetry and continuity cannot both be perfected in the same description. So what is absolutely symmetric must be discontinuous at its limit, and what is absolutely continuous must be asymmetric at its limit. The reason is the inseparability of sameness and difference: in a pairing that holds absolutely, sameness must appear once and difference once in the respect of content, and likewise in the respect of context. Symmetry has sameness of content and difference of context. So the partner of perfected symmetry must have difference of content and sameness of context, and that partner is discontinuity. Continuity has sameness of content and sameness of context. So the partner of perfected continuity must have difference of content and difference of context, and that partner is asymmetry. The four propositions apply the theorem to self and world: one proposition each for the context and the content of the subjective, and one each for the content and the context of the objective.

Subjective context is continuous. The self persists, personal identity endures, and the stream of experience admits no absolute gap. The continuity of subjective context is the most basic feature of what it is to be a self.

Subjective content is discontinuous: thoughts, perceptions and experiences are necessarily diverse. One cannot think the same thought forever. One cannot perceive the same thing always. The content of subjectivity must vary, change, and be multiple.

Objective content is symmetric. The laws of physics are the same everywhere, and energy, momentum and charge are conserved. The structural content of the world is invariant under transformation, and invariance under transformation is the basis of all physical law.

Objective context is asymmetric. Three cases show the asymmetry of objective context: the arrow of time, the gradient of entropy (the physicist's measure of disorder), and the past that is not the future. The frame within which physical events occur has a direction, and that frame does not run backward.

Each of the four propositions is an instance of the Incommensuration Theorem, and the theorem says more than the four propositions do: the theorem says what the other side of each must be. Subjective context is continuous, so subjective context must also be asymmetric: each self is singular, each perspective unrepeatable, each moment of experience its own. Objective content is symmetric, so objective content must also be discontinuous: matter is quantized, energy levels are discrete, and the structural content of the world comes in units. Two pairings survive the theorem as valid absolute conjunctions: continuity with asymmetry, and symmetry with discontinuity. The Introduction calls the two pairings the two survivors of the theorem, and self and world instantiate exactly the two survivors, in that order. In the rest of this essay I take the world side first and then the self side, and I do the new work of the essay on two consequences that I call shadows: quantization, the shadow of symmetry, and uniqueness, the shadow of continuity. Each shadow goes with its law the way an ordinary shadow goes with the object that casts the shadow. The Incommensuration Theorem requires each shadow wherever the law of that shadow is perfected.

IV. Conservation as a Feature of Symmetric Domains

Physicists conventionally understand conservation laws as regularities that experiments discovered and that physicists then gave formal expression, but on the account I am giving, conservation laws have an origin prior to any experiment. Conservation is what symmetry looks like when symmetry is stated as a quantity.

Take the definition: symmetry is sameness of content across difference of context. What is it for a domain (any range of things and conditions that a law covers) to be governed by symmetry? A domain is governed by symmetry when some content stays the same however the context is varied within the domain, and when you name the content that stays the same, you have named a conserved quantity. I have a bottle, I put some water in the bottle, and I put a cork in the bottle. The water is going to stay in the bottle. The water is conserved. Five months might pass, and there is still the same amount of water in the bottle. In the bottle, the content is the amount of water, the context is the passing months, and the symmetry is the sameness of the amount of water across the months. Vary the context in time, and the content that does not vary is energy. Vary the context in space, and the content that does not vary is momentum. Vary the context by rotation, and the content that does not vary is angular momentum. The conservation law is the symmetry itself, in the form of a number that does not change. The conservation law is not something extra that a symmetric domain happens also to obey.

I bring Noether's theorem into the argument at this point, and I want to be careful about the part that Noether's theorem plays. The mathematician Emmy Noether proved the theorem that bears her name in 1918. A system admits a Lagrangian formulation when all of the system's equations of motion follow from one function, the Lagrangian. The action is the Lagrangian added up over the whole history of the system. A conserved current describes how a conserved quantity flows from place to place while the total of the quantity stays the same. For systems that admit a Lagrangian formulation, Noether's theorem establishes that to every continuous symmetry of the action there corresponds a conserved current. Noether's theorem is a theorem of mathematics. The content of Noether's theorem is exact. I claim that Noether's theorem is the formal instance, within one particular and very powerful formalism, of a structural feature that holds of symmetric domains as such. The structural feature is that wherever content is preserved across transformation of context, there is a corresponding conservation, whether or not the domain admits a Lag-

rangian, whether or not the symmetry is expressible as a Lie group (a group of transformations that vary smoothly, such as the rotations), and whether or not anyone has written the current down. I do not claim that the metaphysics re-establishes Noether's result, nor that the metaphysics could. A continuous symmetry is not the forbidden conjunction of symmetry with continuity. The reason is that the symmetry and the continuity hold at two different levels, which the Introduction calls mediation by level. The symmetry is found, as a conserved quantity. The continuity holds of the formalism, as the smooth parameter of the group (the angle of a rotation, for example). Noether's theorem joins the two levels, because Noether's theorem pairs each continuous symmetry of the formalism with a quantity that is found to be conserved (*Incommensuration*, Chapter 10). Noether's theorem shows the physicist exactly which conserved quantity goes with which symmetry, and how to compute that quantity, while the metaphysics shows the physicist why there was going to be a conserved quantity at all.

What a Group Is

Group theory is the part of mathematics that studies patterns and symmetries. The mathematician Nathan Carter gives an intuitive way into group theory in his book *Visual Group Theory* (2009). Carter's way into group theory uses four conditions on a set of actions. First, actions are well defined: the list of possible moves never changes, and the generators for all other actions (the basic moves from which every other action is built) remain constant. Second, actions are reversible: any move can be undone, and any sequence of moves can be undone by reversing the sequence. Third, actions are deterministic, in the mathematical sense: the same action on the same arrangement always gives the same result. Fourth, actions are composable: moves can be combined in any sequence, and any sequence of actions is itself an action, a property that mathematicians call closure. In formal terms, Carter's four conditions correspond to the group axioms of closure, associativity, identity and inverses. Group theory works out the implications of Carter's four observations, and wherever all four of the action conditions hold, the actions form a group.

> The group is the total set of actions generated by the generator set, and not the total set of configurations (the arrangements that the actions produce). When the order in which actions are done makes no difference to the result, mathematicians call the group abelian. Every group can be viewed as a collection of ways to rearrange some set of things.

Why is physical law simple enough to admit conservation laws at all? The more simple a thing is, the more similar the relations of that thing will be to the relations of all other simple things. Simple things are the same as other simple things. Simple things have similar relations and behave in similar ways. So the laws relating simple things are themselves simple, and at the most basic level the diversity of the world reduces to a small number of structural types, whose laws reduce in the same way. A law can hold everywhere because the diversity of the world reduces to a few structural types. A law that holds everywhere is a symmetry law. Where symmetry is the governing type of law, one would expect the fundamental level of the world to be simple, and so the simplicity of the fundamental is not a lucky feature of this world.

V. The Shadow of Symmetry: Quantization

The first new consequence of the Incommensuration Theorem that I draw is quantization.

The content of the world is symmetric. The Incommensuration Theorem states that symmetry and continuity cannot both be perfected together, so symmetric content, followed to its limit, must be discontinuous. Perfected invariance comes in units. Coming in units is what quantization means.

I will go through the argument for quantization more slowly, because the claim that symmetric content must be discontinuous is strong, and I want you to see exactly what the claim depends on. Suppose the content of some domain is invariant under every transformation of context that

the domain admits. Ask whether that invariant content can also vary continuously (be continuous, in the sense of Section I) within a fixed context. If the content could, then the content would be the same whether the context changed or did not change, and so, by the argument of the Introduction, the content would have become independent of the context altogether. The Introduction argues as follows: content and context are each defined against the other, so a content with no dependence on its context cannot be told apart from its context, and the distinction between content and context collapses. When the distinction collapses, the comparison that defines the domain is no longer a comparison. So at the limit a symmetric content is not continuous. A symmetric content is discontinuous, which is to say discrete: the invariant comes as a countable thing, in so many quanta (whole units) of charge, so many units of angular momentum, one electron or two but not one and a half.

When I say that quantization is the shadow of symmetry, I mean the argument just given: content governed by symmetry must be discrete at its limit. Anything governed by symmetry laws must be quantum in character at its limit, so the quantum character of the microscopic world is not an accidental feature of our particular universe, to be accepted as a brute fact and built into the formalism by hand. Wherever physicists have asked for perfect invariance, they have found the discrete, and on the account of this essay they could not have found anything else.

I want to mark the character of the claim that quantization is the shadow of symmetry. My account of conservation was a reading of a known result, while the claim about quantization goes past interpretation: the claim says, before anyone looks, that any domain whose content is governed by symmetry will exhibit discontinuity at its limit. The world we have does exhibit quantization. The quantization of our world is consistent with the claim and, I would say, is what the claim predicts. The claim does not say where the discontinuity falls, how large the quantum is, or which quantities are quantized and which are not in any particular formalism, and this essay does not argue those questions. The question of which charges are exact is not left open, however. I derive the unbroken

symmetries algebraically in my book *Non-Commutative Geometry and the Immanent Metaphysics* (Chapters 5 and 19), and the derivation shows that the unbroken symmetries, the symmetries whose charges are exact, are electromagnetism and color (the charge on which the strong nuclear force acts).

VI. The Limits of Conservation

The Incommensuration Theorem, from which quantization follows, also sets a bound on conservation, and I state the bound in this section.

Perfect symmetry requires discontinuity, and so no conservation law can hold perfectly across all conditions. There will be discontinuities: domain boundaries, phase transitions (such as water freezing into ice), and conditions under which the conservation fails or under which the conserved quantity ceases to be well defined. The bound is a structural statement: the symmetry that a conservation law expresses is a symmetry within a domain, and at the edge of the domain the sameness of content across contexts gives way to something else. The bound is not a prediction that energy will fail to be conserved in the laboratory. Physicists find it difficult to define a conserved total energy for a curved and expanding cosmos, and on my reading that difficulty is an instance of the bound, not a technical embarrassment.

Asymmetry, the complement of symmetry, appears as the differences that conservation cannot eliminate: every conserved quantity has a complementary aspect that is not conserved. Energy is conserved, but the distribution of energy is not. Momentum is conserved, but the direction of a given momentum can change. The total is invariant, and everything interesting happens in what the total does not fix.

What is conserved in one domain may be the asymmetry of another domain, and what is structural and necessary at one scale may be contingent and variable at the next scale. One cannot simply carry a conservation law across a domain boundary and expect the law to hold in the same

form, because what is conserved and what is necessary can differ from one domain to the next. I take up the boundaries themselves in the essays of Part IV, The Boundaries of Physics. In this essay I note only that the bound on conservation and the necessity of quantization are the same fact seen from two sides: symmetry perfected is discontinuous, and discontinuity is where conservation ends.

VII. The Shadow of Continuity: Uniqueness

I turn now from the world side of the assignment to the self side.

The law of continuity is the law of self. Anything that is a self must have three things: the persistence of personal identity, the continuity of consciousness, and the undivided stream of experience. A self must have all three because to be a self is to be governed by continuity, and continuity is sameness of content within sameness of context, which is to say persistence as oneself. So the three things a self must have are not accidental features of a certain kind of biological organism that happened to evolve on Earth.

The Incommensuration Theorem then says what the context governed by continuity must also be: asymmetric. Perfected persistence cannot also be perfected invariance across contexts: a self that persists as itself cannot also be the same as every other self. A self's uniqueness is its difference from every other self. Uniqueness is the shadow of continuity exactly as quantization is the shadow of symmetry.

What would a perfectly symmetric self be? A perfectly symmetric self would be identical to another self: the same content across the difference of context that separates one self from the other. A perfectly symmetric self would also persist: the same content within its own context over time. Identity with another self, together with persistence, is symmetry with continuity, applied absolutely and together, in one and the same thing. Symmetry with continuity is the first of the two conjunctions that the In-

commensuration Theorem forbids. A perfectly symmetric self would violate the Incommensuration Theorem. So there is no perfectly symmetric self.

Every self is therefore unique. Every self is unique for a structural reason rather than a contingent one. The continuity that makes a self a self requires the asymmetry that makes the self this self and no other. Two selves do of course differ in their genes, their histories and their surroundings, but those contingent differences are not the reason that every self is unique. Were the contingent differences all removed, the structural difference would remain, because without the structural difference there would be no self to be the same.

The two shadows, quantization and uniqueness, are the two survivors, and the two survivors fall on opposite sides of the boundary of self. On the world side the survivor is symmetry with discontinuity: invariant content that comes in units. On the self side the survivor is continuity with asymmetry: persistent context that is singular. The Incommensuration Theorem forbids two conjunctions and permits two. Of the two conjunctions that the Incommensuration Theorem permits, symmetry with discontinuity is the structure of the objective, and continuity with asymmetry is the structure of the subjective. The two permitted conjunctions match the two sides of the boundary of self. The match is what the universal law says, seen from the side of the theorem, and so the match follows from the universal law and needs no explaining away.

> **Two Shadows, One Theorem**
>
> Quantization is the shadow of symmetry: the content of world, perfected in its invariance, must be discrete. Uniqueness is the shadow of continuity: the context of self, perfected in its persistence, must be singular. Each shadow is what the Incommensuration Theorem requires of the far side of a survivor, the second member of a surviving pair. Neither shadow is a fact about this world alone.

VIII. Summary

In this essay I make claims of three kinds. Two claims are claims of the metaphysics itself: that every law is a law of symmetry or of continuity, and that symmetry governs world and continuity governs self. One claim is a reading of known physics, a reading that gives the structural reason that a known result is true: the claim that conservation is a feature of symmetric domains, with Noether's theorem as its formal instance. Two claims are consequences of the Incommensuration Theorem, that quantization is the shadow of symmetry and that uniqueness is the shadow of continuity, and these two claims say what any symmetric or continuous domain must show at its limit, before anyone looks.

All law is either symmetry or continuity. Symmetry governs world, continuity governs self, and interaction is where world and self, with their two types of law, meet.

Three things follow from the assignment of symmetry to world and continuity to self, together with the Incommensuration Theorem. Conservation is what symmetry is when symmetry is stated as a quantity, and Noether's theorem is the exact form that conservation takes within the Lagrangian formalism. Quantization is what symmetry must become at its limit, because perfected invariance cannot also be continuous, and so the discrete character of the microscopic is the shadow that symmetry casts, not a peculiarity of this world. Uniqueness is what continuity must become at its limit, because perfected persistence cannot also be perfected sameness across selves, and so the singularity of each self is the shadow that continuity casts, not a peculiarity of biology.

The universal law is the principle that determines what kind of law governs each aspect of reality. The universal law is not a particular law within a particular domain. The Incommensuration Theorem is the prin-

ciple that says what must be found on the far side of each kind of law: discontinuity on the far side of symmetry, and asymmetry on the far side of continuity.

KEY CONCEPTS IN THIS ESSAY

- **Universal law**: all law is either symmetry or continuity; symmetry governs world, continuity governs self; the structural principle governing what kind of law applies where.
- **Law of symmetry**: sameness of content across difference of context stated as law; invariance, conservation; omniscient.
- **Law of continuity**: sameness of content within sameness of context stated as law; persistence, identity; transcendent.
- **Four propositions of being**: subjective context is continuous; subjective content is discontinuous; objective content is symmetric; objective context is asymmetric.
- **Conservation as symmetry**: a conserved quantity is the content that a symmetric domain holds the same across its contexts; Noether's theorem is the formal instance within the Lagrangian formalism.
- **Quantization as the shadow of symmetry**: content governed by symmetry must be discontinuous at its limit; the discrete character of the microscopic is structurally required.
- **Uniqueness as the shadow of continuity**: context governed by continuity must be asymmetric at its limit; every self is singular for a structural reason.
- **The perfectly symmetric self**: a self both persistent and identical to another; the forbidden conjunction of symmetry with continuity; excluded by the theorem.
- **Limit of conservation**: no conservation law holds perfectly across all conditions; every conserved quantity has a complementary aspect that is not conserved; conservation ends where discontinuity begins.

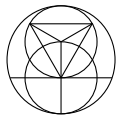
Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.83-1 to 1.83-5 (the universal law); 1.43-8 (the four theorems of being); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.75-13 (objectivity and symmetry, subjectivity and continuity); 1.53-6 (laws, axioms, principles).

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapter on the universal law.

Noether, Emmy. "Invariante Variationsprobleme." *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen* (1918): 235–257.

Carter, Nathan. *Visual Group Theory.* Washington, DC: Mathematical Association of America, 2009.



Essay 2

Determinism and Causality

Why No World Can Be Purely and Completely Deterministic, and What Science Establishes Instead

ABSTRACT

The standard form of determinism asserts that the laws of physics, applied to a complete specification of the state at one time, yield a unique state at every other time. In this essay I argue that the assertion requires two things at once: that the same lawful mapping hold in every context, which is symmetry perfected, and that the state be specified without gap at every point, which is continuity perfected. I state the Incommensuration Theorem in full in the Introduction to this volume, and the theorem holds that symmetry perfected together with continuity perfected is the conjunction that comparison cannot support. Determinism is therefore not false as a matter of fact but unreachable as a matter of structure. I place determinism and pure randomness at the two boundaries of the domain of comparison, the range of all that can be compared: determinism at the macroscopic boundary, and pure randomness at the microscopic boundary. I read the known fragilities of determinism within classical mechanics and relativity (Norton's dome, Earman's catalog) as instances of the conflict between symmetry and continuity. And I draw out an irony: a purely deterministic formal apparatus is what shows that there is no consistent epistemology of determinism in the concrete, that is, no consistent account of how determinism could be known to hold of the concrete world. Science establishes causal law, and not deterministic law,

and the difference between the two kinds of law is the difference between a pattern seen by an observer in time and a specification that needs no observer and no time. I close the essay with the triple of choice, change, and causality, and with the residual (the part of what happens that no lawful description captures) that the theorem requires in any world that admits comparison at all.

Note on framework. This essay depends on the Introduction to this volume, which states the six intrinsics (sameness and difference, content and context, the subjective and the objective), the four secondary compounds (continuity, discontinuity, symmetry and asymmetry), the Incommensuration Theorem in full, and the modal alignment used throughout. This essay also depends on the preceding essay, on symmetry and continuity as the two types of law. I take up two topics of this essay again later: hard randomness, in the essay on hard randomness in Part II, and superdeterminism, in the essay on superdeterminism in Part III. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. What Determinism Claims

Determinism is one of the most persistent ideas in the history of thought. Determinism asserts that the state of the world at any moment is completely and uniquely fixed by the world's state at any prior moment. For anyone with complete knowledge of the present, the whole of the future follows with certainty, and for anyone with complete knowledge of the past, every detail of the present was already settled.

The idea of determinism has real appeal, and the appeal is not foolish. The appeal comes from the experience of lawfulness: similar conditions produce similar outcomes, physical law is reliable, and causes bring their effects regularly. One arrives at determinism by pushing the reliability of physical law to the limit, and by declaring that the regularity is not merely

high but total, not merely approximate but exact, not merely probable but certain. The question of this essay is whether the reliability of physical law can be pushed that far. I will argue that the reliability cannot be pushed that far. The reason is not that the world happens to contain some irregularity. The reason is that the limit of total, exact and certain regularity lies outside the range of everything that can be compared, and so no comparison can ever be made at that limit.

I begin from the standard definition of determinism. In the philosophy of physics, determinism is defined in terms of laws together with initial conditions. Initial conditions are the state of a system at the moment from which one starts. The philosopher of physics John Earman gives the standard definition in his 1986 book *A Primer on Determinism*: a world is deterministic if the laws of physics, applied to a complete specification of the state at one time, yield a unique state at every other time. The philosopher Carl Hoefer adopts the same definition in his survey of the subject. The standard definition is a good definition, and I am going to take the definition exactly as given, without change.

The standard definition asks for two things. First, the definition asks that the laws hold universally across contexts: the same dynamical mapping (the rule by which the state at one time determines the state at another time) applies here and there, now and later, to this system and to that one. In the terms fixed in the Introduction, the content of a comparison is what is being compared, and the context is the frame of the comparison, the respect in which the two things compared are two. The same law in every context is sameness of content across difference of context, which is symmetry. The definition asks for symmetry without exception. The definition also asks that the state be fully specified at every point: no gaps or ambiguities, and no place where the description gives out. A specification without gaps is sameness of content within sameness of context, carried all the way down to every point, which is continuity, and the definition asks for continuity without remainder.

So the standard definition of determinism is a demand for perfect symmetry and perfect continuity in one and the same description. The argument that I make in this essay turns on that demand.

II. The Theorem, Briefly

I state the Incommensuration Theorem in full in the Introduction to this volume, and I will not repeat the whole of the theorem in this essay. In this essay I need only the parts of the Incommensuration Theorem that I set out in this section.

Comparison has six intrinsics, six features that belong to comparison by its nature. The six intrinsics come in three inseparable pairs: sameness and difference, content and context, the subjective and the objective. Applying sameness and difference to content and context gives four compounds. Symmetry is sameness of content across difference of context. Continuity is sameness of content within sameness of context. Asymmetry is difference of content across difference of context. Discontinuity is difference of content within sameness of context. Asymmetry and discontinuity are the complements of symmetry and continuity. The four compounds can be paired in ten ways. When the compounds are applied absolutely and together, that is, when each is made to hold exactly at the foundation of one description, two of the ten pairings are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two pairings survive: continuity with asymmetry, and symmetry with discontinuity. Within any finite domain, symmetry and continuity co-occur to finite degree. But symmetry and continuity cannot both be perfected at once.

The reason for the Incommensuration Theorem is that content which is the same whether the context changes or does not change has no dependence on context at all, and that a comparison in which content and context cannot be told apart is not a comparison. Content and context are inseparable precisely in that each is defined against the other. Perfect symmetry

with perfect continuity leaves the distinction between content and context no work to do, and so the act of comparison that was to be described is no longer there to describe.

The Incommensuration Theorem is not an empirical claim, a claim resting on observation. The Incommensuration Theorem does not depend on quantum mechanics, on chaos, on the uncertainty relations, or on any experiment. The theorem depends on what comparison is. The Root Tautology of the Introduction is the recognition that interaction, comparison and relation are one act, named three ways. By the Root Tautology, comparison is interaction, and interaction is what physics is about.

III. Determinism as the Forbidden Conjunction

Once the Incommensuration Theorem is stated, the argument against determinism is short. I want the argument to be short, because the force of the argument is in its simplicity.

Taken precisely, determinism asserts that there can be a complete and absolute specification of all values of all content for all values of all context, independent of any observer. Determinism requires no reference to a subjective standpoint, the position of someone making a comparison. The lack of any standpoint is what makes determinism determinism rather than prediction. Determinism claims that the specification is everywhere continuous: no gaps, no missing values, no point at which the state is left open. And determinism claims that the specification is everywhere symmetric. The same laws hold in every context, and the same mapping from prior state to subsequent state operates universally.

Determinism is therefore the assertion of total symmetry and total continuity, applied simultaneously and without remainder. Total symmetry with total continuity is the first forbidden conjunction of the theorem, exactly as the theorem names it, without alteration.

So no world is purely and completely deterministic. The conclusion does not depend on the results of any experiment. The conclusion does not depend on quantum mechanics, on chaos theory, on the uncertainty principle, or on any particular formalism. The conclusion depends only on the structure of comparison. Determinism fails because the concept of determinism, carried to completion, collapses the distinction between content and context that comparison requires in order to be comparison. A world that admits no comparison is not a world in which anything is determined, because a world that admits no comparison is not a world in which anything is anything.

I want to rule out one misreading before the reader makes it. The argument does not say that the world is irregular, that the laws of physics are unreliable, that experiments do not repeat, or that the future is not very largely fixed by the past. In the argument against determinism I hold only that the claim of totality fails: regularity cannot be complete, specification cannot be without gap, and regularity and specification cannot both be perfected in one description. Within a finite domain, a description can be very symmetric and very continuous, and the whole success of physics lies within finite domains. The theorem concerns the limit at which symmetry and continuity would be perfected. Determinism is a claim about that limit, so the theorem applies to determinism.

The argument also has a self-referential turn. Anyone who tries to reject the Incommensuration Theorem instantiates the structure of comparison that the Incommensuration Theorem describes. To argue that comparison has no intrinsic structure, one must compare the structured account of comparison with an unstructured account. The comparison uses content, context, sameness, difference, a standpoint and a referent. A determinist who wishes to dispute this essay must make a comparison, and in making it the determinist supplies everything that the argument needs.

IV. Determinism at the Macroscopic Boundary, Pure Randomness at the Microscopic

If determinism does not hold of the world, where does determinism belong? Determinism belongs at the boundary of the very large, and pure randomness belongs at the boundary of the very small.

The Introduction names two boundaries of the domain of comparison, the range within which anything can be compared at all. The macroscopic limit is the limit of the very large. The speed of light sets the macroscopic limit, and from beyond the macroscopic limit no signal arrives. The microscopic limit is the limit of the very small. Planck's constant marks the microscopic limit: below the action that Planck's constant marks, no measurement distinguishes jointly what a pair of conjugate quantities would need to fix. Action is a physical quantity, and Planck's constant is a fixed amount of action. Position and momentum are a pair of conjugate quantities: no description of a state is sharp in both position and momentum. By a boundary I mean exactly an edge past which there is no coherent signal, and from beyond either edge there is no meaningful measurement, and so nothing that can be compared, and so nothing that can be known.

Determinism represents what lies beyond the macroscopic boundary. Determinism is the view from everywhere at once: the whole of the state across the whole of the context, the domain seen as a completed object with no standpoint inside the domain. The omniscient modality is the mode of structure, of what holds regardless of who looks. Determinism is the omniscient modality pushed past the edge of what can be measured. Determinism, if it could hold, would have to be made good all the way to the scale of the absolute microscopic, the scale of exactly zero, because the claim of determinism is that nothing is unaccounted for at any scale, however small. Pure randomness represents what lies beyond the microscopic boundary. Pure randomness is complete indeterminism, and pure randomness is an abstraction, as determinism is. Something can cross into the

domain from below the microscopic limit, and anything that crosses cannot appear as anything other than random, because nothing about the thing that crosses could have been compared before the crossing. Hard randomness is what crosses from below the microscopic limit: the remainder that every comparison leaves, real, and inside the domain. I develop the idea fully in the essay on hard randomness in Part II, and this essay needs only the little that I say in this section.

Between the two edges, the macroscopic boundary and the microscopic boundary, there is a spectrum. Four concepts that matter to this essay lie along the spectrum: determinism, pure randomness, causality and choice. Determinism is the claim that everything can be predicted, always: nothing is unaccounted for. Pure randomness is the condition in which nothing can be predicted at all, so that everything is unaccounted for. Causality is the condition in which most things can be predicted most of the time. Choice lies between causality and pure randomness: choice is a condition in which some of what happens follows from what went before, and some of what happens does not, and both parts are real.

I want the reader to see that determinism and pure randomness are both limits, and that neither limit is inside the domain. The world we can compare is neither determinism nor pure randomness. The world we can compare is the middle of the spectrum: causal, and open. The world is open in that some of what happens is not fixed by what went before. Hard randomness, by contrast, is real and is found inside the domain, so hard randomness is not a limit. The determinist takes one edge of the domain for the whole, and the pure indeterminist takes the other edge for the whole. Both mistake a boundary for a territory. Each treats an edge of the domain, where nothing can be compared, as though the world were found there.

One further distinction belongs in this section, because the distinction between the atemporal and the temporal is the one most often lost. Determinism is atemporal, that is, outside time. The complete specification that determinism imagines is not a specification at a time, in a place, from a standpoint, but the whole laid out at once, in the manner of a mathemat-

ical object. Causality is temporal: causality is a pattern seen by an observer who is somewhere and somewhen, looking from a past that is known toward a future that is not yet. Most physicists find atemporality entirely comfortable, because the models that physicists work in are atemporal and the models work. I regard the comfort of physicists with atemporality as a mistake, and I will say why in the next two sections. But I want to record that the mistake is one that a physicist can make while remaining perfectly consistent within the model. The mistake is not a logical inconsistency. The inconsistency is philosophical: the physicist's argument is valid, in that its conclusion follows from its premises, and the argument is not sound, in that its premises are not all true of the world.

V. Norton's Dome and the Fragility of the Formalisms

The philosophical literature contains several results showing that determinism can fail within the formalisms most often assumed to guarantee determinism, classical mechanics and relativity, and I want to read the results in the light of the Incommensuration Theorem. The results are not the argument of this essay, but a reader who follows the argument would expect determinism to fail somewhere within classical mechanics and relativity.

The cleanest case is Norton's dome, which the philosopher of physics John Norton set out in a paper of 2008. A particle sits at the apex of a dome. The dome is shaped so that the force on the particle grows as a fractional power of the particle's distance from the top. Newton's laws of motion admit the solution in which the particle sits at rest forever, and Newton's laws also admit solutions in which the particle sits at rest for some arbitrary time and then, without any cause, begins to slide down in some arbitrary direction. The equations are satisfied throughout and the initial state is fully specified, and yet the future is not unique. In the language of the mathematics, the force law fails to be Lipschitz continuous at the apex. When the change in the force between any two positions is never

more than a fixed multiple of the distance between the two positions, mathematicians call the force law Lipschitz continuous. The uniqueness result for the equations of motion requires Lipschitz continuity. The uniqueness result is the theorem which shows that each fully specified initial state has exactly one future.

I now read Norton's dome in the terms of this essay. On the dome the laws are perfectly symmetric: the same equations hold everywhere, at every time. Determinism fails exactly where the specification is not perfectly continuous: at one point, the apex, in the slope of the force law. When perfect continuity fails by that much, at one point only, perfect determinism fails too. Norton's dome is a case in which perfect symmetry and perfect continuity were being asked for together and could not both be had.

Earman catalogs more cases. One of Earman's cases is the space invaders. In Newtonian mechanics with unbounded velocities, a particle may arrive from spatial infinity in finite time, so the state on any bounded region at one moment does not fix the state of the region later, because something can come in from outside. The space invaders show that the specification is incomplete under laws that remain perfectly symmetric, and an incomplete specification is a failure of continuity in the sense of this essay. A second case is the non-Hausdorff spacetimes. In a non-Hausdorff spacetime, a single history can branch into two histories that cannot be told apart at the branching point. In a non-Hausdorff spacetime the context itself fails to be continuous. A third case is the hole argument in general relativity. In the hole argument, the same physical situation admits many mathematically distinct descriptions, which agree everywhere outside a region and differ inside the region. So general relativity, as a description, fails to determine what happens inside the region, unless one gives up something about what the points of its formalism refer to. General covariance is the requirement that the laws of general relativity take the same form in every system of coordinates. The hole argument is a case in which symmetry, carried to its limit in the form of general covariance, makes the specification no longer unique.

I did not find the dome, the space invaders, the non-Hausdorff spacetimes or the hole argument: the four cases are results of Norton and Earman and of the physics and mathematics that Norton and Earman draw on. I am not adding to the four results. I claim that the Incommensuration Theorem says why there had to be results like the dome and the other three cases. Determinism requires a conjunction that cannot be perfected. So any formalism that is pressed toward determinism will give way at some point, failing there to fix a unique future. And a formalism will give way at a point where symmetry and continuity have been asked to hold together at the limit. Each of the four cases is a breakdown at a point where symmetry and continuity were asked to hold together at the limit. Writers on determinism have found the four cases one at a time and have treated each case as a curiosity. On my reading, the four cases are one conflict, between perfect symmetry and perfect continuity, showing through in different places.

VI. The Irony of Determinism

The argument against determinism contains an irony, and I stop to consider the irony because the irony is more than amusing. The irony is the shape of the whole situation: the irony shows how a formal description is related to the world that the formal description is about.

I make the argument against determinism with instruments that are themselves deterministic. Mathematics is deterministic, and logic is deterministic. The uniqueness result for well-behaved differential equations is a piece of exact reasoning. Norton exhibited the failure of the uniqueness result at the dome, and Norton's exhibition is exact reasoning too. The Incommensuration Theorem itself is an argument from definitions, valid at every step. Mathematics and logic are purely deterministic methods, and in the abstract and the symbolic they formally establish that there is no internally consistent epistemology of determinism in actual concrete reality. An epistemology is an account of how something is

known. So no internally consistent account can be given of how determinism could be known to hold of the concrete world. The apparatus by which we describe the world guarantees that the world is not fully describable by that apparatus.

The world is not fully describable by the apparatus that describes the world, and this limit on description is not a failure of physics. The limit on description is a structural feature of the relation between formalism and reality, and any metaphysics adequate to physics (any account of what is real at the most basic level) has to account for the structural feature rather than explain the feature away. On the account I give, a formalism is a system of relations. Relations are the mathematics of comparison, and relations are atemporal, symmetric and exact. Reality is a system of interactions. Interactions are comparisons that occur somewhere, somewhen, from a standpoint, and interactions are temporal, asymmetric and finite. The Root Tautology says that relation and interaction are one act seen from two sides, but the Root Tautology does not say that relation and interaction are the same side of the act. So a formalism can describe the limits on interaction with perfect exactness and still not be an interaction, and the thing that the formalism describes need not be as exact as the description.

General relativity and quantum mechanics both show the relation between formalism and reality, and I say more about both theories in the essay on measurement as interaction, in this part of the volume. General relativity is a theory of the limits of signaling: who can signal whom, from where and when to where and when. Quantum mechanics is a theory of the limits of information content: who can know what, and when. Both theories are theories of access, of what can be measured and what cannot, and both theories are defined in a formal, deterministic manner. Yet the two theories bound an information content that need not itself be deterministic, even though the theories describing the bounds are deterministic. A perfectly exact fence does not make the field inside the fence exact, and in the picture of the fence the two theories are the fence and the informa-

tion content that the theories bound is the field. The irony of determinism is that the fence was mistaken for the field. Determinists took the exactness of the theories to be exactness in what the theories bound.

In Section IV I said that the comfort of physicists with atemporality is a mistake that one can make consistently, and the reason is that, within the formalism, determinism is a platonic truth (a timeless truth, of the kind that holds of mathematical objects). Determinism is what the relations, taken as relations, say. The mistake is to carry the truth of the relations across to the interactions without noticing the crossing: from the atemporal to the temporal, from the symmetric to the asymmetric, and from what needs no observer to what cannot occur without an observer. Nothing in the formalism licenses the crossing, and the Incommensuration Theorem forbids the crossing but does not forbid the formalism.

VII. What Remains: Causality, Not Determinism

That determinism is impossible does not entail that causality is impossible. The whole practical weight of this essay depends on keeping determinism and causality apart.

Causality asserts a consistent pattern of observed relations between events, as perceived by an observing self. Three features of the definition of causality make causality different from determinism. First, causality requires reference to an observer, and determinism explicitly requires none. Second, causality is time-asymmetric: causes precede effects, and the pattern is read from the past toward the future. By contrast, determinism is atemporal. Third, causality makes no claim about the complete microscopic specification of all events, and determinism is that claim. Causality says: similar conditions reliably produce similar outcomes. Causality does not say: all conditions produce unique, fully specified outcomes for all time.

Science can establish causality. Science cannot establish determinism, and I mean "cannot" in the strict sense: no possible method could establish determinism. The scientific method involves an implicit assumption of symmetry: repeatable experiments give the same results. But no method can verify that symmetry universally, because verification is itself a finite set of comparisons. And no method can verify that the content is everywhere continuous, because every measurement has a resolution. The resolution of a measurement is the smallest difference that the measurement can tell apart. The claim that science can make is causal law, not deterministic law. The restriction to causal law is not a limitation on science that a better science would remove. The restriction is what science is: science is a system of comparisons made from standpoints, and the Incommensuration Theorem says that no system of comparisons can be carried to the limit that determinism names, perfect symmetry together with perfect continuity.

The theorem also states the structural reason that causality is achievable where determinism is not. Causality involves symmetry: a causal pattern repeats across different contexts, or the pattern would not be a pattern. Causality does not require total continuity. A causal pattern needs a specification good enough to see the pattern by, and not a specification complete at every point. Causality is exactly a finite degree of symmetry together with a finite degree of continuity, and that combination is exactly what the theorem permits. There is a second reason, at the level of absolute application, where the theorem states which pairings can hold exactly. Causation's own pairing is continuity with asymmetry: a connection without a break, along an order that runs one way. Continuity with asymmetry is one of the two pairings that the theorem permits (the other is symmetry with discontinuity). So when determinism fails, causation remains in place of determinism, and not nothing. Every world that admits comparison at all is therefore to some positive degree causal, and the positive degree is zero-positivity at work. Zero-positivity is a consequence of the three axioms of the Introduction, and zero-positivity is the principle that the fundamental measures of every domain have an absolute minim-

um but no absolute maximum. And the Incommensuration Theorem says that no world is purely and completely deterministic. There is no tension between the statement about causality and the statement about determinism. The statement about causality and the statement about determinism describe the same structure, seen from inside the domain and from the edge of the domain.

The confusion of causality with determinism is not random: the confusion follows a usual path of three steps. First, change is collapsed into causation: the process of transition is identified with the lawful pattern of transition. Then choice is collapsed into causation: whatever is not explained by the pattern is declared to be an instance of the pattern not yet understood. Once change, choice and causation are all collapsed into one, causation is identified with determinism, and causation and determinism are treated as strict isomorphs, that is, as corresponding feature for feature without exception. Each step feels harmless, and the last step, which identifies causation with determinism, is the one that produces the mistake. A philosopher knows that change, choice, causation and determinism have to be different. A physicist works inside a model in which change, choice, causation and determinism are not different. The physicist is not wrong about the model. The physicist is wrong about what the model is a model of.

VIII. Choice, Change, and Causality

If determinism is impossible, then there is always a residual: a domain of reality that is not captured by lawful structural specification. The Incommensuration Theorem guarantees the residual: because symmetry and continuity cannot both be perfected, there will always be aspects of what occurs that no structural description, however complete, can exhaustively render.

I want to be exact about what kind of residual the theorem requires. The residual is not epistemic ignorance, a lack in what we know: the residual is not a gap in what we happen to know that a more powerful theory or a finer instrument could in principle fill. The residual is the gap that the theorem requires. The residual is there in any world that admits comparison, for the same reason that comparison is possible at all. In every world that admits comparison there is a dimension of genuine novelty: something that is not fixed by prior conditions, not obtainable from structural law, and not reducible to mechanism.

In this book's metaphysics the residual is called choice, and choice forms a triple with change and causality. Choice, change and causality, the three members of the triple, are distinct, inseparable, and non-interchangeable. The triple of relation, domain and identity is distinct, inseparable, and non-interchangeable in the same way, and so is the triple of the three modalities (the omniscient, the transcendent and the immanent). The Introduction states the third axiom in plain words: no one of the three can be reduced to the others, each of the three occurs only together with the others, and any substitution of one for another is a mistake. Causality is the lawful, repeatable pattern, and causality has the nature of the omniscient. Choice is the emergence of the new, the singular act that is only itself, and choice has the nature of the transcendent, the mode of the generative, of what makes a domain possible. Change is the actual process of transition, the interaction in which pattern and novelty meet. Change has the nature of the immanent, the mode of process. Change is also the superclass of causality and choice: every causal pattern and every choice is a change.

The concept of choice is conjugate with the concept of causality with respect to the concept of change. Neither concept can be reduced to the other or defined away. Causality therefore implies potentiality: where there is lawful order, there are other possibilities besides the one that actually occurs, and potentiality is a concept of choice. Choice is as much a way of accounting for change as causation is. Choices cannot be predicted, because a choice that could be predicted would be causal and not choice.

To collapse choice into causality is to claim that novelty is illusion, that the appearance of the new is always and only the unfolding of what was already implicit in the old. The Incommensuration Theorem says that the collapse of choice into causality cannot be carried through. Choice, change and causality remain three. And the impossibility of the collapse is what makes superdeterminism, determinism extended to the choices of observers, not merely false but malformed. Superdeterminism extends the deterministic claim to include the measurement choices of observers: the superdeterminist asserts that the apparent freedom to choose what to measure is itself fixed by prior conditions shared with the system being measured. If determinism is impossible, superdeterminism is impossible a fortiori (all the more surely). The reason is that the superdeterminist asks for everything the determinist asks for, and then for more. The more that the superdeterminist asks for is that choice itself be causation. Choice as causation is precisely the collapse of one member of the triple into another, and by the structure of the triple that collapse is a category error, the mistake of treating something of one kind as something of another kind. I take up superdeterminism in full in the essay on superdeterminism in Part III.

I can show why the triple must be a triple from the side of the self rather than the side of the world, and I find this way of seeing more illuminating than the abstract statement. Suppose a person has choice but the person's choices have no effect: nothing that the person chooses makes any difference to anything else. Where choices have no effect, causation is absent. Where choices have no effect, choice is also absent, because a choice that changes nothing was not a choice of anything. Now suppose the opposite: everything the person does affects everything, and every act ramifies without limit. Then there is no free choice either, because any move at all carries too much, and the person is bound. The first case, choices without effect, is a case of no symmetry: the act does not carry across contexts. The second case, acts that ramify without limit, is a case of too much continuity: the act carries without break into everything.

Choice exists where there is enough of symmetry and of continuity and not all of either, which is exactly where the Incommensuration Theorem says anything at all can exist.

> **On the Kind of Impossibility Claimed**
>
> I argue in this essay that determinism is impossible, and the impossibility is structural, and neither empirical nor logical. The impossibility is not logical, because a fully deterministic mathematical object is perfectly consistent as an object. The impossibility is not empirical, because I cite no experiment and the argument needs none. The impossibility is structural: the description that determinism asks for cannot be the description of a comparison, and a world is what comparisons are of. The conclusion depends on the Incommensuration Theorem and the Root Tautology. The theorem and the Root Tautology are each used in any denial of either, because to dispute either statement one must compare, and comparison has the structure that the two statements state.

IX. Summary

The central claim of this essay is that no world is purely and completely deterministic. The central claim is a structural exclusion: the claim says what physics will not find, and the claim says so before anyone looks. Two other claims of this essay are readings of known results: the claim that science establishes causal law and not deterministic law, and the readings of the dome, the space invaders and the hole argument. Each reading states the structural reason that a known result is true. The world is causal and is not deterministic, and the argument of this essay depends on keeping the two claims distinct.

Determinism is structurally unreachable. The standard definition requires that the same laws hold in every context and that the state be specified without gap at every point, and the two requirements together are symmetry perfected together with continuity perfected. The Incommen-

suration Theorem holds that symmetry perfected together with continuity perfected is the one conjunction that no description of a comparison can support. Determinism requires both. Determinism therefore cannot hold.

The impossibility of determinism is not empirical: the impossibility is not a consequence of what has been observed. The impossibility is a consequence of what comparison is, and comparison is interaction, and interaction is the act of every physical event. The structure of comparison constrains the structure of physics, and the constraint is that total regularity and total specification cannot coexist. Where total regularity is pushed past its limit, one comes to the macroscopic boundary and the view from nowhere, and where total specification is pushed past its limit, one comes to the microscopic boundary and pure randomness. The world lies between the two boundaries, and the world is causal, and open.

So there is always a residual: a domain of genuine novelty, of irreducible choice, of the authentically new. The residual is a feature of the structure of reality, not a deficiency in the world and not a deficiency in physics, and the residual is the same feature that makes physics possible at all. The universe is not a machine. The universe is a process: lawful, causal, and irreducibly open.

KEY CONCEPTS IN THIS ESSAY

- **Determinism**: the assertion that laws applied to a complete state at one time yield a unique state at every other time; read as the demand for total symmetry and total continuity together; structurally unreachable by the theorem.
- **Causality**: a consistent pattern of observed relations between events, as perceived by an observer; temporal, asymmetric, requiring finite symmetry and finite continuity; its own pairing, continuity with asymmetry, is one the theorem permits; structurally achievable, and what science establishes.

- **Pure randomness**: complete indeterminism, a content found different whatever its context; the condition beyond the microscopic boundary, the opposite limit to determinism; an abstraction, excluded by the theorem as determinism is.
- **Hard randomness**: the irreducible remainder that every comparison leaves, an outcome not fully determined by prior structure; what arrives through the microscopic boundary, where nothing could have been compared before it arrived; real, and inside the domain.
- **The two boundaries**: the macroscopic edge (no signal arrives) past which determinism would live, and the microscopic edge (no measurement distinguishes) past which pure randomness would live; the world is between them.
- **Norton's dome**: a Newtonian system with non-unique solutions arising from a failure of Lipschitz continuity in the force law; read as symmetry and continuity asked for together at the limit.
- **The irony of determinism**: that purely deterministic formal methods are what establish there is no consistent epistemology of determinism in concrete reality; the fence mistaken for the field.
- **Atemporal and temporal**: determinism is a claim about the whole laid out at once; causality is a pattern read from a standpoint in time; the mistake is to carry the first across to the second.
- **Choice, change, causality**: the foundational triple; distinct, inseparable, non-interchangeable; causality omniscient, choice transcendent, change immanent and the superclass of the other two.
- **The residual**: the domain of genuine novelty that the theorem requires in any world admitting comparison; not epistemic ignorance but structural openness.
- **Superdeterminism**: determinism extended to the choices of observers; impossible a fortiori, and a category error in collapsing choice into causality.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.45-1 (distinct, inseparable, non-interchangeable); the sections Choice, Change, and Causality, and Causality and Determinism (Technical Appendix).

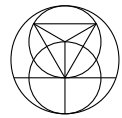
Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Earman, John. *A Primer on Determinism.* Dordrecht: D. Reidel, 1986.

Hoefer, Carl. "Causal Determinism." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta. Spring 2016 edition.

Norton, John D. "The Dome: An Unexpectedly Simple Failure of Determinism." *Philosophy of Science* 75, no. 5 (2008): 786–798.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.



Essay 3

Measurement as Interaction

On Relation, Access,
and the Determinacy of the Observed

ABSTRACT

The concept of measurement is, in every case, the concept of interaction under a particular description, so that whatever is epistemically true of measurement (true of it as a way of coming to know) is true of interaction. In this essay I develop the identification of measurement with interaction from the basic notion of comparison, and I follow the identification into five consequences. The first consequence is that every measurement reifies three distinctions, past from future, here from there, and actual from potential (to reify a distinction is to make the distinction concrete in an act), and so every measurement has a subjective side and an objective side that cannot be removed from the account of measurement. The second consequence is that interaction is prior to existence, reality and objectivity, each of which is confirmed only by the possibility of engagement. The third consequence is that a relation laid out as structure exists while an interaction is real, and therefore that mathematics is not physics, so that a physics which claims to describe what lies beyond all measurement has stopped doing physics without thereby doing metaphysics. The fourth consequence is that quantum mechanics can be read as a theory of the limits of information content and general relativity as a theory of the limits of signaling flow: the two theories are two access controls, each stated in a deterministic formalism that says nothing about whether what

is accessed is determined. The fifth consequence is that theories which posit an unprivileged interface over a privileged reality are self-contradictory, and that the cat in the thought experiment of the physicist Erwin Schrödinger is indeterminate for the outside not because looking disturbs the cat but because determinacy is a relation that only an interaction can instantiate.

Note on framework. This essay depends on the Introduction to this volume. The Introduction states the six intrinsics of comparison (sameness and difference, content and context, the subjective and the objective), the four secondary compounds (continuity, discontinuity, symmetry and asymmetry), the Incommensuration Theorem, the three axioms, and the modal alignment used throughout. This essay prepares the ground for the essay on the six measures, which follows this essay. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Measurement Is Interaction

I state the identification of measurement with interaction in one line in my book *An Immanent Metaphysics*: the concept of a measurement is isomorphic with the concept of an observation, a perception, and an interaction. To say that the four concepts of measurement, observation, perception and interaction are isomorphic is to say that the four concepts correspond to one another feature for feature. I take the isomorphism as a foundational claim, and not as a manner of speaking. The isomorphism means that every measurement is also an interaction, and that every property of measurement as such is a property of interaction as such. The methods we use to come to know the world are not separable from the methods by which the world acts upon itself.

The identification of measurement with interaction is grounded in comparison. A comparison is a comparison of interactions, and not a comparison of things. There are no purely static things to be compared. Whatever presents itself for comparison presents itself by acting, by being acted upon, and by making a difference somewhere. In the terms of the Introduction, content is what is being compared, and context is the frame of the comparison. What we call a thing is a stable pattern in a field of interaction: a content held the same across some range of contexts, and the stability of the pattern is what makes the thing available to be compared at all.

In *An Immanent Metaphysics* I state three consequences together with the identification, and each consequence has a counterpart in physics. The first consequence is that one cannot observe just one thing. Every observation is a comparison. A comparison requires at least two things: the reading and the scale, the sample and the standard, or the signal and the background. If a measurement were of one thing alone, with nothing for the thing to differ from, the measurement would be the absence of a measurement. Because a comparison requires at least two, every measurement in physics is a ratio: a count against a unit or a difference from a reference.

The second consequence of the identification is that one cannot not observe at least one something. There is no null observation. A detector that registers no event has still registered. The absence of a click is an outcome that the apparatus was configured to be able to produce. To be an observer at all is to be already in interaction. There is no position outside interaction from which the interacting could be surveyed.

The third consequence of the identification is that one cannot completely observe any one thing. No measurement exhausts what it measures. Every interaction transfers some content and leaves other content untransferred. The untransferred content cannot be measured jointly with what was transferred, and is not merely content that has not yet been measured. Where the incompleteness of observation takes the form of un-

certainty, I treat the physics of uncertainty in the essay on the microscopic boundary, in Part IV. The incompleteness is intrinsic to the concept of observation, and not a deficiency of any instrument.

Measurement is a case of interaction in one exact sense: measurement is interaction under a particular description. In a measurement, one side of the interaction is taken as the measurer and the other side as the measured, and the content transferred from the measured to the measurer is taken as representative of the measured. The interaction itself carries no labels of measurer and measured: the one who measures supplies the labels. Whatever limit holds on interaction holds on measurement, and whatever holds on measurement holds on interaction, because a limit on measurement holds on the concept of measurement and not on the instrument.

II. Three Distinctions

When measurement is taken as interaction, any notion of measurement is a reification of three distinctions: the past from the future, the here from the there, and the actual from the potential. If the three distinctions are removed from the notion of measurement, the notion of measurement is removed too.

To measure at all, one must distinguish what was from what will be. A measurement yields a record, and a record is of what has happened. The record is used for a prediction, and a prediction is of what has not yet happened. Every instrument reading can be distinguished from the state the instrument will have a moment later, since otherwise the reading would not be a reading. The interaction of measuring has a before and an after, and the after differs from the before.

To measure at all, one must also distinguish what is proximate from what is distant. The apparatus is here, and the sample is there. The measurer is not the measured. Even where the measurer and the measured are

in contact, the contact is a boundary, and a boundary is a here on one side and a there on the other, so where something has been measured, something has been distinguished as elsewhere.

Third, to measure at all one must distinguish what has been actualized from what remains in potentia (what is still only potential). A measurement has an outcome, and an outcome is one among several alternatives, the others of which did not obtain. A reading that could have been nothing else carries no information, because the reading was a foregone conclusion and not an outcome. The actual is actual against a space of possibility, and the measurement is what selects within that space.

The three contexts of measurement are the three distinctions, past from future, here from there, and actual from potential, and in the next essay I name the three contexts time, space and possibility. Time is the context in which past differs from future. Space is the context in which here differs from there. Possibility is the context in which actual differs from potential. The three modalities of the Introduction are the immanent (the mode of process), the omniscient (the mode of structure) and the transcendent (the mode of the generative and the potential). In the alignment of modalities fixed for this volume, space and the pattern that occupies space are omniscient, time and the force that flows through time are immanent, and possibility and the probability weighted within possibility are transcendent. So the three distinctions are one distinction for each modality, and to consider any measurement is to consider all three distinctions, at least implicitly.

Each distinction has a subjective side and an objective side. The objective is an apparency (a way of appearing) of what has happened, what obtained and what is laid out for any comparer to read. The subjective is an apparency of the stance from which the objective is read: a stance situated in one present, at one here, before a range of what could be found, of what has not yet happened, and of what might obtain. The two sides are consistent with the alignment of the book, in which the object is omniscient (existence, pattern, what is settled and shareable) and the subject is tran-

scendent (possibility, choice, what is not yet settled). At the human scale the relation among future, potential and otherness is the felt meaning behind choice.

To give each distinction a subjective side is not to psychologize physics, that is, to reduce physics to psychology. Instead, I observe that the structure of measurement, which is the foundation of physics, necessarily implicates both a measured and a measurer. If a physicist tries to remove the measurer from the account of measurement, the account is left incomplete. The incompleteness has consequences for operations, not merely for philosophy. When a physicist tries to write down only the objective side, the physicist will find that the formalism has quietly retained the subjective side: in the choice of variables, in the choice of basis, and in the choice of what is to count as a system.

III. Interaction Before Existence

Consider what one has to assume before one can say that something exists, or that the thing is real, or that the thing is objective. In each of the three cases the answer is the same: some possibility of confirmable engagement. If I can interact with a thing, if I can measure the thing, or if there is some way in which the thing could make a difference to me and I to the thing, then I can assert that the thing exists, or that it is real, or that it is objective. In every one of the three cases, whoever makes the assertion takes interaction as prior in order to establish existence, reality or objectivity.

The priority of interaction is the first axiom seen in practice, and the first axiom states that the immanent is more fundamental than the omniscient and/or the transcendent, and that the omniscient and the transcendent are in conjugate relationship to one another. Interaction is immanent, existence is omniscient, and objectivity is transcendent. Reality is the plural of what is real: everything that is real, taken together. Reality is immanent, because what is real is what is encountered in interaction. To

exist is to have a place in a pattern: to be repeatable, locatable and shareable, the kind of thing a third person could be told about. To be objective is to hold across perspectives: to be what any observer would find. A statement of what any observer would find is a claim about the space of possible observers, and so a claim about possibility. To be real is to be encountered, here and now, in this interaction. Existence, objectivity, and reality are distinct, inseparable, and non-interchangeable, as the third axiom requires: the third axiom says that the classes and the instances of the immanent, the omniscient, and the transcendent are distinct, inseparable, and non-interchangeable. There are things that are real which do not exist: they are encountered, but they have no place in any pattern. And there are things said to exist that have a place in a formalism but have never been encountered.

Perception is an interaction, and so perception is immanent. The perceived is an object, so the perceived is omniscient, while the perceiver is a subject, so the perceiver is transcendent. By the first axiom, it follows that the process of perception is more fundamental than either the perceiver or the perceived. I can see from inside my own perceiving that the process of perception is more fundamental than either the perceiver or the perceived. I can perceive what is the object of perception. I cannot perceive the perceiver: when I try, what I find is another object. I cannot perceive the perceiving either, because the perceiving is not among the things perceived. Of perceiver, perceived and perceiving, I can perceive only the perceived. Light does not perceive light: two beams cross in a region of space, and the wavefronts pass through one another with nothing registered. An interaction is not itself an interactant, one of the things that interact. An interaction is its own class of being, in the way that the relation between is and is-not is neither something that is nor something that is not; and the relation between is and is-not must be of a deeper order than either is or is-not.

One can model a perception as a channel. The channel has three parts: a world that produces a signal, a signal traveling through a medium, and a self on the receiving end. The self takes the content that flows through

the channel as representative of the perceived. In *An Immanent Metaphysics* I distinguish two directions of interaction, perception and expression. In perception the flow of change is from the objective toward the subjective, the dynamic is one of abstraction, and overall details are removed. In expression the flow of change is from the subjective toward the objective, the dynamic is one of instruction (to instruct is to put into structure), and overall details are added.

A measurement is a perception in this sense: a flow of change from the objective toward the subjective, in which details are removed. A measurement abstracts. The pointer reading is the residue of an enormous quantity of detail that the apparatus has discarded on the way to the reading. Discarding detail is what measurement is: a measurement extracts a content from a context and leaves the context behind. So the discarding of detail is not a limitation to be overcome. Preparing an experiment, by contrast, is an expression: the experimenter puts structure into the world and only then reads back what the world returns. Every experiment is an expression followed by a perception, and the pairing of the expression with the perception is what makes the experiment a test.

IV. The Relation That Exists and the Interaction That Is Real

A relation in mathematics exists as structure, and not as an interaction. A relation in mathematics is a sameness or a difference of content held across contexts: timeless, repeatable, re-readable, defined, and laid out. So a relation in mathematics has the nature of the omniscient, the mode of structure. An interaction is an event: here and now, irreversible, and unrepeatable in its particularity. So an interaction has the nature of the immanent, the mode of process and of the here and now. A relation in the full sense is real, because a relation in the full sense is given in an interaction between the things it relates, and a relation in the full sense is one act with that interaction and with the comparison. The Root Tautology of the Intro-

duction says that interaction, comparison and relation are one act, named three ways. The structure laid out and the act that is real are distinct, by the third axiom (the three modalities are distinct, inseparable and non-interchangeable), and the act that is real is the more fundamental of the two, by the first axiom (the immanent is more fundamental than the omniscient and/or the transcendent). A law exists, while a measurement is real.

To take mathematics for physics is to take the structure that exists for the act that is real. Mathematics is, and cannot not be, founded on patterns of relation laid out as structure. Physics is, and cannot not be, founded on patterns of interaction. Mathematics is useful when it is applied to physics, but the usefulness does not make mathematics and physics the same, at either the epistemic level (the level of knowing) or the ontological level (the level of being). The bond between physics and measurement is tight: there is no physics without measurement. The bond between mathematics and number is tight: there is no mathematics without relation among its objects. A structure laid out is bound to the interaction it describes, but the bond between structure and interaction is strictly weaker than either the bond between physics and measurement or the bond between mathematics and number. Structures model interactions, but structures do not become interactions. A model of an interaction is a relation among the interaction's abstractions, and abstraction has removed the very thing that made the interaction an event.

The difference between structure and interaction has a consequence for the scope of physics. Insofar as physics is founded on measurement, physics cannot be regarded as transcending the concepts that measurement requires. When a theory claims to describe something beyond all possible measurement, the theory has stopped doing physics. Nor has the theory thereby started doing metaphysics, because metaphysics is the study of the structure of comparison that physics already is. Only what could be reached by some comparison can be the basis of an assertion, in physics or out of it.

When I say that a theory has stopped doing physics, I do not rebuke the theory. We assess a claim about what is in principle beyond measurement in four ways: by the claim's consistency, by whether the claim respects the categories it uses, by what the claim makes intelligible, and by whether the claim has quietly borrowed the authority of physics for a position that physics cannot reach. Three claims are claims about what no comparison could reach. The first claim posits a multiplicity of unobservable worlds taken as literal existents. The second claim posits a wave function taken as a thing in itself, prior to and independent of every interaction. The third claim posits a set of hidden variables held to be in principle inaccessible. A hidden variable is a quantity, beyond those of quantum mechanics, that would fix each outcome in advance. None of the three claims is physics. Existence with no possible interaction is indistinguishable from non-existence (*Comparison*, Chapter 12). So what each of the three claims posits is indistinguishable from nothing. I take up the reverse question, about the metaphysics rather than about physics, in the essay on what physics cannot reach, in Part IV of this volume: what can and cannot be seen from the position of the metaphysics itself.

V. Two Theories of Access

I give a reading of general relativity and of quantum mechanics. In a reading, as the Introduction explains, I take a result that physics has already established as an instance of the structure of comparison. The reading says what kind of theory each one is, in the terms this book uses, and the reading alters neither theory.

General relativity is a theory of the limits of signaling flow. General relativity is a model of who can signal whom, from one where-when to another where-when. A where-when is a place at a time: what physicists call an event. The primary object of general relativity is the light cone: the bound of what a signal from an event can reach. General relativity has a metric, the rule that determines the separation between events, and the

metric is, before it is anything else, a statement of which events can be connected by an interaction and which cannot. General relativity is inherently a theory of macroscopic interactions, and the theory describes them from the outside in: the whole of spacetime is laid out, and the observer surveys spacetime as a structure of possible connections.

Quantum mechanics is a theory of the limits of information content. Quantum mechanics is a model of who can know what, and when. The commutation relations of quantum mechanics are statements of which pairs of quantities can be jointly definite, and the quantum state is a catalog of what an interaction could yield and with what weighting. Quantum mechanics is inherently a theory of microscopic interactions, and quantum mechanics describes microscopic interactions from the inside out. The observer is within the domain, receiving what each interaction delivers, and quantum mechanics says what can be delivered.

In the alignment fixed for this volume, symmetry is omniscient and continuity is transcendent. In each of the two great theories, physicists apply one of the two characters (symmetry or continuity) to the domain proper to the other character. Signaling flow is a matter of connectedness: whether one event can be reached from another without crossing a boundary. Connectedness is continuity. General relativity is continuity-with-asymmetry applied to the macroscopic, the omniscient domain. Information content is a matter of what stays the same and can therefore be counted: invariants, quantum numbers, and exchange-indistinguishable particles (particles of one kind, any two of which can be exchanged with nothing changed). What stays the same is symmetry. Quantum mechanics is symmetry-with-discontinuity applied to the microscopic, the transcendent domain. The Incommensuration Theorem says that when any two of the four compounds (symmetry, asymmetry, continuity and discontinuity) are applied absolutely and together, two conjunctions are forbidden, symmetry with continuity and asymmetry with discontinuity, while two survive as valid absolute conjunctions, continuity with asymmetry and symmetry with discontinuity. General relativity and quantum mechanics are the two valid absolute conjunctions, and in each theory physicists

carry the character proper to one modality into the domain proper to the other modality, a crossing that the Introduction calls the cross-modal reach. I give the reason that the reach is required rather than accidental in the essay on cross-modal reach, in Part III.

Both theories are access controls, in this sense: each theory states a limit on what can be perceived or measured. General relativity limits what can be signaled between where-whens, and quantum mechanics limits what can be known of a what. Both theories are also stated in a formal, deterministic manner. In general relativity, the field equations evolve the metric deterministically. In quantum mechanics, the wave equation evolves the state deterministically. Yet the information content that the two theories bound need not itself be deterministic. When the limits on what can be known are described deterministically, the description does not establish that what is known was fixed in advance. Each formalism is a map of the access controls, and the map says nothing about whether the territory (what is accessed) is determined.

I develop an irony in the essay on determinism, earlier in this Part: purely deterministic methods, in the abstract and the symbolic, can formally establish that there is no internally consistent epistemology of determinism in actual concrete reality (epistemology is the study of knowing). We describe the world with a formal apparatus, and the formal apparatus guarantees that the world is not fully describable by that apparatus. The incompleteness is a structural feature of the relationship between formalism and reality, and between relation and interaction, and not a failure of physics. Section IV gives the reason to expect the incompleteness: structures model interactions, but structures do not become interactions.

VI. The Interface Objection

Some theorists hold three claims together. The clearest example of their family of theories is the interface theory of perception, which the cognitive scientist Donald Hoffman proposed. The first claim is that

everything we perceive comes to us through an interface. The second claim is that no interface is privileged, since each interface is shaped for the needs of the perceiver rather than for the truth of the perceived. In the sense of the second claim, a privileged interface would be one shaped for the truth of the perceived. The third claim is that there is nonetheless a privileged fundamental reality, and that the interfaces conceal it. The structure of the three claims also appears in physics whenever someone says that the true reality is some formal object, and that measurement is only our species-limited view of that formal object.

The structure of the three claims contains a contradiction, which I state exactly: if no interface is privileged, but there is a privileged level of reality, then somewhere along the way there must be a translation from the privileged level to the interface. Ask of the translation: is the translation real, or is it not?

If the translation is real, the translation is an interaction: something that actually happens between the privileged level and the interface. A real translation is then privileged, in exactly the theory's sense of the word, because the translation is what actually occurs. The theory then contradicts itself: by the theory's own account of how the interface comes to be, something at the interface is privileged.

If the translation is not real, then the privileged level has no connection to any interface. Then no one can state the claim that the privileged level underlies the interfaces. The reason is that to underlie the interfaces is exactly to have the connection that has been denied. Where a privileged reality has no real relation to what is perceived, the privileged reality is a posit (a thing assumed) with no route to the one positing it, and not a reality that is being perceived through an interface.

Whether the translation is real or not, the interface theory contains an internal inconsistency, and the inconsistency must be resolved before anyone can take the theory seriously as a foundation for physics or for epistemology. I resolve the dilemma by rejecting the premise that both branches share, rather than by choosing one branch. The shared premise

is that what is privileged is a level. What is privileged is the interaction, and not a level. There is no fundamental reality beneath the interface. Nor is any interface merely unprivileged. There is interaction, which is real, and existence and objectivity are abstractions of interaction. The first axiom says directly that interaction comes first: the immanent is more fundamental than the omniscient and/or the transcendent. When a theory makes some omniscient structure fundamental and makes interaction derivative, the theory has inverted the first axiom. The translation problem is the form that the inversion of the first axiom takes.

VII. The Cat

In 1935 the physicist Erwin Schrödinger proposed a thought experiment. Schrödinger's thought experiment places a cat in a sealed chamber with a small quantity of radioactive substance, a counter, and a flask of poison that the counter will release if a decay is registered. After an hour, the formalism of quantum mechanics describes the whole system as a superposition (one quantum state that combines two states) of decayed and not-decayed, and so of dead and living. Schrödinger intended the picture as an absurdity: a reason not to take the superposition literally at the scale of a cat.

Two responses to the cat have become standard. The first response is the disturbance reading: the cat is either dead or alive, we do not know which, and looking either finds out which or forces the matter. The second response is decoherence: the cat is already in constant interaction with its surroundings, the surroundings act as a measurer, and the superposition is destroyed long before anyone opens the box. I accept decoherence as a description of mechanism, and I reject the disturbance reading as an account of what is at issue. But I give one reason that bears on both responses, and neither response gives that reason for itself.

Under the three axioms of the Introduction, perfect closure is impossible: every domain has some relation to what is outside it. Existence with no possible interaction is indistinguishable from non-existence, so a domain with no external relations would have no existence relative to anything outside itself. In thermodynamics a closed or isolated system is an idealization: a system whose exchanges with its surroundings are small enough to neglect. The impossibility of perfect closure shows the role of observation in physical theory. Observation is any interaction that relates a system to what is outside it, and observation is the condition for a system to have a determinate state relative to what is outside the system, and not an external addition to an otherwise self-sufficient system.

Determinacy is a relation, because to have a definite state is to be a content within a context, and a content within a context is established by comparison, which is interaction. Until an interaction relates the cat to the outside, the outside has no fact of the matter about the cat, because a fact for the outside names a relation between the cat and the outside, and that relation has not yet been instantiated. The reason is not that a fact is hidden, since a hidden fact presupposes the fact. The reason is not that looking would disturb a fact either, since a disturbed fact presupposes the fact too. Observation is structurally required for determinacy in the way that a difference is required for a comparison. The word "definite" applies to something only where there has been an interaction.

Whoever holds the disturbance reading assumes a prior determinate value that the measurement reveals or perturbs. I reject exactly the assumption of a prior determinate value. The physicist John Bell proved Bell's theorem, which I take up in the essay in Part II. Bell's theorem shows that the assumption of a prior determinate value cannot be held together with locality, the principle that no influence travels from one place to another faster than light. I reject the assumption from above (from the concept of comparison), while Bell rejects the assumption from below (from the correlations between measurements). The two rejections, from above and from below, agree.

Inside the chamber, the cat is not in doubt. Everything in the chamber is in interaction throughout: the atom, the counter, the flask and the cat interact with one another. Relative to the interactions within the chamber, there is determinacy inside the chamber. The determinacy inside the chamber is relative to the interaction in which the determinacy is established, and the interaction inside the box is not the interaction across the wall of the box. The relativity of determinacy to an interaction is the recognition that a fact is a content in a context, and that the context is supplied by an interaction, not by a view from nowhere (a view from no standpoint at all). So the relativity of determinacy is not relativism about facts: interaction is real, and by the first axiom, which makes the immanent more fundamental than the omniscient and/or the transcendent, interaction is the most fundamental thing there is.

On my reading of the cat, decoherence is the observation that was always already happening, and not an alternative to observation. The environment of the cat is an interacting partner like any other, and any interaction is a comparison. I therefore expect macroscopic superpositions to be found fragile, for a structural reason. The structural reason is that a large system is one that is in a great many interactions, and each of those interactions instantiates the relations that a superposition requires to be absent. The fragility of macroscopic superpositions is an expectation of the reading, not a calculation, and the calculation belongs to the physics.

On my account, the quantum state exists as the description of possibility: the range of outcomes a given setting could yield, each with its weight. A quantum state prior to measurement is therefore not a particular outcome. Measurement actualizes one outcome from the range of possible outcomes, and does not reveal a pre-existing particular. The actualizing of one outcome is my account of what physicists call the collapse of the wavefunction. On my account, the collapse is the passage from the possible to the actual in the act of comparison, after which the outcome is a new finding, and the new finding supersedes the earlier quantum state. The collapse is not a physical process that destroys a superposition.

I say plainly what the reading leaves undecided. The reading does not decide between collapse formalisms and no-collapse formalisms (formalisms in which the quantum state never collapses). Does the reading mean that things are only there when we look at them? Is the moon only there because we are looking at it? No. The moon interacts all the time, with sunlight and with everything near it. The moon is definite relative to its own interactions. No person needs to look at the moon for the moon to be definite. The reading does not make consciousness the agent of determinacy: any interaction will do, and a Geiger counter is as good a measurer as a physicist. The reading says what determinacy is, and the reading says that the puzzle of the cat arises from asking for a determinacy where the relation that would constitute a determinacy has not yet been made.

VIII. Summary

Three claims that I make in this essay are claims of the metaphysics itself. The three claims are that measurement is interaction under a description, that interaction is prior to existence, reality and objectivity, and that a relation laid out as structure exists while an interaction is real. Other claims that I make in this essay are readings of known physics. I read General Relativity as a theory of signaling limits and Quantum Mechanics as a theory of information limits. I also read the cat as a case of relational determinacy. Each reading gives the structural reason a known result or puzzle has the shape it has. The expectation that macroscopic superpositions are fragile is an expectation about kind, not about magnitude.

Measurement is interaction. Whatever is true of measurement is true of interaction, and whatever is true of interaction is true of measurement. Physics rests on measurement, so physics rests on interaction and cannot get beneath interaction.

Every other claim of this essay follows from the identification of measurement with interaction. Every measurement has a subjective side that no formalism removes. Interaction is prior to existence, to reality, and to

objectivity. A relation laid out as structure is not an interaction, so mathematics models physics without becoming physics. For the same reason, a physics that claims to reach beyond every measurement has stopped being physics without becoming metaphysics. The two great theories, general relativity and quantum mechanics, are theories of access, general relativity a theory of signaling and quantum mechanics a theory of knowing. The determinism of the formalisms of general relativity and quantum mechanics is the determinism of maps, not of territories. When a theory puts a privileged reality beneath unprivileged interfaces, the theory cannot say whether the passage between the reality and the interfaces is real. And the cat is indeterminate for us because being determinate for us is a relation that our looking makes, and not because we have not looked, nor because looking would disturb the cat.

Physicists have always known that every measurement involves an interaction. From the metaphysics I add two things. The first thing that I add from the metaphysics is that the bond between measurement and interaction is the definition of what one is doing in measuring, not a practical constraint on instruments. The second thing that I add from the metaphysics is that the whole of physics is the study of what interaction, as such, permits and forbids.

KEY CONCEPTS IN THIS ESSAY

- **Measurement as interaction**: the concept of measurement is isomorphic with observation, perception, and interaction; every property of measurement as such is a property of interaction as such.
- **The three distinctions**: past from future, here from there, actual from potential; the three contexts that any measurement reifies; time, space, and possibility.
- **Interaction before existence**: to exist, to be real, and to be objective are each confirmed only by the possibility of engagement; the first axiom met in practice.

- **The relation that exists and the interaction that is real**: a relation laid out as structure is a re-readable sameness or difference across contexts, and exists; an interaction is an unrepeatable event, and is real; a relation in the full sense is given in an interaction and is one act with it; mathematics rests on the first and physics on the second.
- **Physics beyond measurement**: a theory that describes what lies beyond all possible measurement has stopped doing physics, and has not thereby started doing metaphysics, which is the study of the structure of comparison that physics already is.
- **Access controls**: general relativity read as a theory of the limits of signaling flow; quantum mechanics read as a theory of the limits of information content; both deterministic as formalisms, neither establishing that the accessed is determined.
- **The interface dilemma**: an unprivileged interface over a privileged reality requires a translation between them; if the translation is real it is privileged, if not the reality is unconnected; the resolution is that interaction, not a level, is what is privileged.
- **Relational determinacy**: to be definite is to be a content in a context, which only an interaction instantiates; the cat is indeterminate for the outside because the relation has not been made, not because it is hidden or would be disturbed.

Materials Reviewed

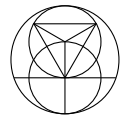
Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.43-6, 1.43-7 (measurement isomorphic with observation, perception, interaction; the intrinsics of being); 1.85-3, 1.85-5 (the six intrinsics of interaction; perception and expression); 1.85-8 (the six intrinsics of measurement); 1.3-1 (the three axioms).

Schrödinger, Erwin. "Die gegenwärtige Situation in der Quantenmechanik." *Naturwissenschaften* 23 (1935): 807–812, 823–828, 844–849.

Bohr, Niels. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 48 (1935): 696–702.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Hoffman, Donald D. *The Case Against Reality: Why Evolution Hid the Truth from Our Eyes*. New York: W. W. Norton, 2019.



Essay 4

The Six Measures and the Six Intrinsics

On Mass, Space, Force, Time,
Probability, and Possibility

ABSTRACT

Any concept of an event of measurement involves six intrinsics: mass, space, force, time, probability, and possibility. In my book *Comparison; The Necessary Basis* I set out the six intrinsics of measurement, which I call the six measures, and argue their correspondence, member by member, with the six intrinsics of comparison. The six intrinsics of comparison are the six features that belong to every act of comparison by its nature. In this essay I take the next step: I close the chain of correspondences from comparison to measurement by supplying the term in the middle of the chain, which is interaction. Measurement is interaction under a description, and interaction has its own six intrinsics. In my book *An Immanent Metaphysics* I state the six intrinsics of interaction as what any interaction between self and reality must involve. The six intrinsics of interaction are the distinction of subject and object, the fixed characteristic of the object, the irreversibility of change, the direction of the flow of change, the transformation of information, and the specification of what that transformation adds or removes. The six intrinsics of interaction correspond one to one with the six measures, so the six measures are the six intrinsics of comparison read through two descriptions: comparison described as an interaction, and interaction described as a measurement. I arrange the six measures in a grid of three modal columns and two rows: the grid has

one column for each of the three modalities (the omniscient, the immanent and the transcendent), and one row of content and one row of context. I show that the content row is governed by symmetry law and the context row by continuity law. I then follow the Incommensuration Theorem to its consequence: content must be quantized at the absolute microscopic scale of a domain, and context must be continuous at the absolute macroscopic scale. I close by saying what kind of claim each result of the essay is.

Note on framework. This essay depends on the Introduction to this volume, on the essay on the two types of law, and on the essay on measurement as interaction that precedes this essay. In this essay I build on the argument for the six measures in *Comparison; The Necessary Basis*, Chapter 8, without restating that argument. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Three Six-Fold Systems

I build on an account of comparison that I call the metaphysics, and the metaphysics contains three six-fold systems that bear on physics. I begin by saying exactly which system is which.

The first system is the six intrinsics of comparison: sameness and difference, content and context, the subjective and the objective. The six intrinsics of comparison are the six features that belong to every act of comparison by its nature. Content is what is being compared, and context is the frame within which the comparison is made. The six intrinsics of comparison are the root: every other structure in this book is an instance of the six intrinsics of comparison. I state the six intrinsics of comparison in the Introduction to this volume.

The second system is the six intrinsics of interaction. In my book *An Immanent Metaphysics* I hold that any consideration of interaction, of perception or expression between self and reality, will ultimately rest on and

resolve into exactly six aspects, irreducibly intrinsic to the consideration itself. In perception the flow of change runs from the objective toward the subjective, and in expression the flow runs the other way. The six intrinsics of interaction are what the six intrinsics of comparison become when comparison is taken as an event, and comparison taken as an event is an interaction between a self and a world, and not a relation among contents. So the six intrinsics of interaction are a second system, and not the six intrinsics of comparison restated.

The third system is the six intrinsics of measurement, which I call the six measures. Any concept of an event of measurement will involve mass, space, force, time, probability, and possibility, and all six will be considered, at least implicitly, in any consideration of any measurement. The six measures are the six that physics handles as its quantities. More exactly, the six measures are the six kinds of quantity that any physical quantity is a species of.

The three systems are related by description, in two steps. Comparison, interaction and relation are one act named three ways, and interaction is that one act described as an event. Measurement is interaction taken under a further description. In a measurement, one side of the interaction is the measurer and the other side is the measured, and the content transferred from the measured to the measurer is taken as representative of the measured. I developed that description of measurement in the previous essay, on measurement as interaction. So the six measures are the six intrinsics of comparison read through two descriptions: comparison described as an interaction, and interaction described as a measurement. If the two readings are sound, the six measures are the old structure seen from the position of physics, and not a new structure. I call the six measures the physical face of the six intrinsics, meaning the six intrinsics of comparison seen from the position of physics.

In *Comparison; The Necessary Basis* I argue, member by member, that the six measures correspond with the six intrinsics of comparison (Chapter 8). I make that argument in the focus of comparison as relation: the framing in which comparison as a relation is in view. The omniscient, the im-

manent and the transcendent are the three modalities that the Introduction describes: the omniscient is the mode of structure, the immanent is the mode of process, and the transcendent is the mode of the generative. In the focus of comparison as relation, sameness is mass and difference is space, and mass and space are the omniscient pair. The objective is force and the subjective is time, and force and time are the immanent pair. Content is probability and context is possibility, and probability and possibility are the transcendent pair. In this essay I work in the focus of measurement, where the six measures are bound to the six intrinsics of comparison by role. Pattern (mass) and space are bound to content and context, force and time to sameness and difference, and probability and possibility to the subjective and the objective. The two bindings are peers, related by a rotation in which each pair of intrinsics moves to the next pair of measures. Sameness and difference move from the omniscient pair to the immanent pair, the subjective and the objective move from the immanent pair to the transcendent pair, and content and context move from the transcendent pair to the omniscient pair. Neither of the two bindings of the six measures to the six intrinsics of comparison corrects the other binding. What this essay adds is the term in the middle, between comparison and measurement. In this essay I supply the intermediate six, the six intrinsics of interaction, and I show that the correspondence between comparison and measurement passes through the six intrinsics of interaction one to one. When the correspondence passes through interaction one to one, the chain from comparison to measurement closes. The alignment of comparison with measurement is then seen to be the composition of two alignments: comparison to interaction, and interaction to measurement. Each of the two alignments, comparison to interaction and interaction to measurement, can be checked on its own.

II. The Six Measures

The six measures need only a brief statement in this essay, since I develop each measure in *Comparison* (Chapter 8).

I use the word mass with the combined meanings of inertia, pattern, form, shape, and structure. Mass in that combined sense is what persists, what resists change and what a measurement finds to be there. Space is the setting within which pattern is located: in one place rather than another, and in one configuration rather than another.

Force is the coupling between things: the mechanism by which one thing engages another, and the intensity and direction of change. Time is the medium through which change proceeds: the order of before and after, and the sequence of the steps of a measurement.

Probability is the weighting of outcomes given what is known: the degree to which each outcome is expected. Possibility is the space of outcomes: what could obtain, the set of alternatives against which any actual outcome counts as one of the alternatives.

If any one of the six measures is removed, no act of measurement is left. Without pattern there is nothing to measure, and without space there is nowhere for the pattern to be. Without force there is no engagement of one thing with another, and without time there is no process. Without probability there is no assessment of outcomes, and without possibility there is nothing to assess. The removal of each measure in turn is the first part of the argument that there are six measures. In *Comparison* I complete the argument by deriving the count of six as three roles taken twice, once as content and once as context (Chapter 8, and Chapter 5, Section VIII).

The International System of Units, the SI, has since 2019 fixed each of its units by the exact value of a defining constant. The defining constants are the speed of light c, the Planck constant h, the elementary charge e, the Boltzmann constant k, the Avogadro constant N_{A}, the luminous efficacy K_{cd}, and the frequency of a transition of the cesium atom, which fixes the

second. The definitions make some units depend on others, and the dependencies form a tree whose root is time: time stands alone, and the unit of time depends on no other unit. Space depends on time (through c). Mass depends on time and space (through h). Charge depends on time (through e). Temperature depends on time, space, and mass (through k). Luminous intensity depends on time, space, and mass (through K_{cd}). Amount of substance depends on no other unit (through N_A). Luminous intensity and amount of substance are conventions layered on top of the tree. The kilogram remains among the base units of the SI by name, but the definition of the kilogram runs through h. So in the SI mass is fixed through h, the meter and the second, and mass is not a base of its own (*Measurement; The Steps from Comparison to Physics*, Chapter 7, Section II). Charge is a side branch of the tree.

In the SI the unit of force is derived from the unit of mass: the newton is the kilogram meter per second squared, through the physicist Isaac Newton's second law of motion, which says that force equals mass times acceleration. So in the SI's table of units force is a composite of pattern, space and time. In the grid of the next section, force is the immanent content. Force is the directed flow of change: the push or pull that changes how something moves. In the same grid, pattern is the omniscient content: what is there, laid out. Pattern, in this sense, gathers mass, inertia and structure (*Measurement; The Steps from Comparison to Physics*, Chapter 3, Section II). In the Introduction I set out three axioms. The first of the three axioms, Axiom I, states: "The immanent is more fundamental than the omniscient and/or the transcendent" (*Incommensuration; The Theorem and the Three Axioms*, Chapter 3, Section II). When I read the SI's order of derivation in the grid, the order runs against Axiom I. The reason is that the SI builds the immanent content (force) from the omniscient content (mass). In the chain of the defining constants, the SI already treats mass as derived, and not as a base of its own: the kilogram is fixed through h, the meter and the second. In the reading by the chain of defining constants, e (the elementary charge) is the constant that brings force into the

system of units. Charge enters physics as what electric force acts on, and the ampere, the unit that *e* fixes, is a rate of flow of charge: a measure of the act of the force in time (*Measurement; The Steps from Comparison to Physics*, Chapter 7, Section II). In the same reading, mass is then derived, fixed by the constants already introduced, so in the re-ordered reading force is among the cells of the grid that a defining constant brings in. The two readings are the same in operation. Newton's second law holds in either reading, and every equation has the same form in both readings. What changes between the two readings is the choice of the quantity written as fundamental and of the quantity written as composite.

III. The Grid

The six measures can be grouped in two ways, and the two groupings cut across one another, so that when both groupings are applied at once, the six measures fall into a grid of three columns and two rows.

The columns of the grid are modal: each column has the nature of one of the three modalities. The measures of mass in space have the nature of the omniscient, the measures of force in time have the nature of the immanent, and the measures of probability in possibility have the nature of the transcendent. The grouping into columns follows the modal alignment that the Introduction fixes for this volume. In the modal alignment, the omniscient is the structural, the repeatable, existence and pattern. The immanent is the processual, the interactive, change. The transcendent is the evaluative, the potential, choice and possibility. I write each column as a content in a context on purpose: mass *in* space, force *in* time and probability *in* possibility.

The rows of the grid are content and context. In *An Immanent Metaphysics* I group the six measures into those that represent content aspects of a measurement and those that represent context aspects. Pattern, force, and probability are content. Space, time, and possibility are context. A class concept is the concept of a kind, and an instance concept is the

concept of one case of the kind. When the concept in view is physicality, the class concept of content is composed of the instance concepts of mass, force, and probability, and the class concept of context is composed of the instance concepts of space, time, and possibility. In *An Immanent Metaphysics* I call each of the two classes a triaxial: three axes making up one class.

The Grid of Measures

	Omniscient	**Immanent**	**Transcendent**
Content	mass	force	probability
Context	space	time	possibility

The grid has three columns (one for each modality) and two rows (content and context). The omniscient column is mass (content) in space (context). The immanent column is force (content) in time (context). The transcendent column is probability (content) in possibility (context). Read across, the content row contains mass, force and probability. The context row contains space, time and possibility. Every measurement occupies all six cells, at least implicitly.

The grid shows what each grouping alone hides. The modal columns say what kind of thing each pair is: structural, processual, evaluative. The content and context rows say what role each measure plays within its pair. Content and context are two of the six intrinsics of comparison, the second of the three pairs of intrinsics, so the rows are the second pair of intrinsics showing up inside the six measures, and not a classification imposed from outside. In the next section, the other two pairs of intrinsics, sameness and difference and the subjective and the objective, show up inside the six measures in the same way.

IV. The Six Intrinsics of Interaction

In *An Immanent Metaphysics* I state the six intrinsics of interaction in a fixed order, and for each intrinsic I give its modality and whether the intrinsic is a content or a context. In this essay I take the six intrinsics of interaction in that fixed order. For each intrinsic I name the measure that the intrinsic corresponds to. The correspondence is a claim I make in *An Immanent Metaphysics* itself. The six intrinsics of interaction have direct one to one correspondence with the six intrinsic measures of any physical domain, because the essential nature of all measurement, as in the method of science, is itself necessarily an interaction.

The first intrinsic of interaction is the distinction of subject and object, of the patterned and the patternless, of form and feeling. The distinction of subject and object is an omniscient modal context: a context that has the nature of the omniscient. In all interactions there is always a difference, a discontinuity, between the subjective and the objective. The distinction of subject and object corresponds to space. Space is the measure of the separation between subject and object: the measurer is not the measured, and the measurement is made across a distance, even where the distance is the thickness of a boundary. In *An Immanent Metaphysics* I add that the subjective and the objective are discontinuous with each other yet in symmetric relationship to each other: each is what the other is not, and neither is privileged over the other in the distinction itself. Space has both features, the discontinuity and the symmetry. Two points in space are distinct (the discontinuity), and the relation between the two points is the same from either end (the symmetry).

The second intrinsic of interaction is the fixed characteristic of the structure of the object, which I call the platonic eternity in *An Immanent Metaphysics*, after the unchanging forms of the philosopher Plato. The fixed characteristic is an omniscient modal content. In all interactions there is always a degree of objectivity, a symmetry, with fixed characterist-

ics, and the fixed characteristic corresponds to mass, in the combined sense of inertia, pattern, form, shape, and structure. Mass is what stays the same through the interaction: the mass that resists acceleration, the pattern that is recognized across encounters, the structure that one measurement finds and that a second measurement finds again.

The third intrinsic of interaction is the irreversibility of change. The irreversibility of change is an immanent modal context. In all interactions there is always a subjective irreversibility, an asymmetry. The irreversibility of change corresponds to time. Time is the context of change. The defining feature of time is that before is not after and cannot be made into after. In *An Immanent Metaphysics* I say that the irreversibility of change is met within continuity: change is continuous, and within the continuity of change there is a direction that does not reverse.

The fourth intrinsic of interaction is the direction of the flow of change. The direction of the flow of change is an immanent modal content. In all interactions there is always a flow of change with direction and degrees of intensity. The direction of the flow of change corresponds to force. Force is directed and has magnitude. Force is the content of change: what flows, in what direction, and how strongly.

The fifth intrinsic of interaction is the transformation of information. The transformation of information is a transcendent modal context. In all interactions there is always a dynamic of abstraction or of instruction: detail is removed as the interaction moves from world toward self (abstraction, as in perception), or detail is added as the interaction moves from self toward world (instruction, as in expression). The transformation of information corresponds to possibility. Possibility is the space within which detail is added or removed: the range of what could obtain, narrowed by abstraction to what has been perceived, and widened by instruction to what has been specified. Possibility is the context of the transcendent column because possibility is the context of the transformation itself.

The sixth intrinsic of interaction is the specification of the transformation's attributes: the addition of non-local and non-deterministic detail, of what I call gauge values in *An Immanent Metaphysics*. The specification is a transcendent modal content. In all interactions there is always a specification of the details that are added or removed. The specification corresponds to probability. Probability is the weighting of specified alternatives. Probability is what is said about an outcome that no law fixes in advance: the content that the transformation adds over and above what the symmetric and continuous structure determines. In *An Immanent Metaphysics* I describe the content that the specification adds as non-local and non-deterministic, and the description is no accident, because probability is the measure in which the transcendent, the creative, the chosen, enters measurement.

The six intrinsics of interaction correspond to the six measures as follows. The distinction of subject and object corresponds to space, and the fixed characteristic corresponds to mass: the omniscient context and content. Irreversibility corresponds to time, and the direction of flow corresponds to force: the immanent context and content. Transformation corresponds to possibility, and specification corresponds to probability: the transcendent context and content. So the grid of Section III is reproduced exactly, column for column and row for row.

In *An Immanent Metaphysics* I add one more layer to the correspondence. The intrinsics of distinction and fixed characteristic are defined in terms of causality, the intrinsics of irreversibility and direction in terms of change, and the intrinsics of transformation and specification in terms of choice. Causality is omniscient, change is immanent, and choice is transcendent. So the three columns of the grid are the columns of causality, change, and choice. As physics is ordinarily practiced, physicists work in the first two columns and handle the third column by probability alone, with possibility left implicit as the space over which the probabilities are defined. I think that the single most consequential thing the grid has to

say is that the third column is where choice enters measurement. I develop that point elsewhere in this book and in my book *The Structure of Effective Choice*.

V. The Two Rows and the Two Laws

In the essay on the two types of law I established that every law is a law of symmetry or a law of continuity. The grid shows the type of law that governs each row.

Where pattern, force and probability are the content of a perception, these three measures will be defined by symmetry law. Where space, time and possibility are the context of a perception, these three measures will be defined by continuity law. So the content row is the symmetry row, and the context row is the continuity row.

One should expect the assignment of the two laws to the two rows from the definitions of symmetry and continuity. Symmetry is sameness of content across difference of context. A law of symmetry is therefore a law about content: about what stays the same as the context varies. Conservation laws are the physics of the content row: mass is conserved together with energy, as one currency; force is conserved as momentum; and probability is conserved as the normalization of the state, which keeps the probabilities of all the outcomes adding to one. Continuity is sameness of content within sameness of context. A law of continuity is therefore a law about context: about the setting remaining the setting, with no gap in the setting. The physics of the context row is the physics of the continuum: space that admits no absolute gap, time that admits no absolute pause, and possibility that admits no absolute exclusion in advance.

Now apply the Incommensuration Theorem to the two rows of the grid, the content row and the context row. The four secondary compounds of the Introduction are continuity, discontinuity, symmetry and asymmetry, and to apply a compound absolutely is to hold the compound

exactly, at the foundation of a description. In the form fixed in the Introduction, the Incommensuration Theorem says: when any two of the four secondary compounds are applied absolutely and together, symmetry with continuity is forbidden, and asymmetry with discontinuity is forbidden, while continuity with asymmetry, and symmetry with discontinuity, are the two conjunctions that survive. Within any finite domain symmetry and continuity co-occur to finite degree: what they cannot do is both be perfected at once.

In *An Immanent Metaphysics* I draw the consequence of the theorem for the grid in three steps. First, that which is known or defined as symmetric must also be discontinuous, since the Incommensuration Theorem forbids anything to be regarded as both wholly symmetric and wholly continuous. Second, the concept of discontinuity is isomorphic with the concept of quantization (the two concepts correspond feature for feature), so that the concept of content has common basis with quantization, and the concept of context has common basis with non-quantization. Third, at the absolute microscopic scale of a domain, the pattern, force, and probability aspects of a perception must be quantized: symmetric and discontinuous. At the absolute macroscopic scale of a domain, the space, time, and possibility aspects of a perception must be continuous: non-quantized and asymmetric.

The two rows of the grid are therefore the two survivors of the theorem, the two conjunctions that the theorem allows. The content row, at its limit, is symmetry with discontinuity. The context row, at its limit, is continuity with asymmetry. Neither row can be both survivors at once. The grid as a whole is two structures, and not a single structure that could be perfected in one description: the two structures are held together only in the interaction that occupies all six cells, and never in what one description finds of all six perfectly.

The phrase *at the absolute scale* restricts the consequence of the Incommensuration Theorem to limits: the consequence is about the limits of a domain, and the consequence does not say that content is quantized everywhere and context continuous everywhere. At the human scale,

mass looks continuous and space looks divisible, and both appearances are true to finite degree. When a domain is pushed to its microscopic boundary, the content measures must show their discontinuity, and when the domain is pushed to its macroscopic boundary, the context measures must show their continuity. In the alignment fixed for this volume, the microscopic domain is transcendent and the macroscopic domain is omniscient, and each domain is where the tool proper to the other modality is applied. At the microscopic boundary physicists apply symmetry, the tool proper to the omniscient. At the macroscopic boundary physicists apply continuity, the tool proper to the transcendent. Part IV of this book is about the two boundaries themselves.

The character of the modalities themselves is consistent with the two claims about the limits: that content is quantized at the microscopic limit, and that context is continuous at the macroscopic limit. The omniscient in its own character is the quantized and the macroscopic, and anything actual is quantized. The transcendent in its own character is the non-quantized and the microscopic, and anything potential is continuous (*Comparison*, Chapters 5 and 12). At a limit, physicists find what the tool that they bring to the limit shows. At the microscopic limit physicists bring symmetry (the omniscient tool) and find the discrete outcome, which is the actual. The amplitude between outcomes, which is the potential, stays continuous. An amplitude is the quantity in quantum mechanics from which the probability of each outcome is computed. At the macroscopic limit physicists bring continuity (the transcendent tool) and find the unbroken, directed context.

VI. Why This Is Not Analogy

A reader may object that an alignment like the alignment in this essay is a pattern found by looking for a pattern. On that objection, someone has taken six things from one place and six from another, and has lined the two sets up. I want to say why the alignment is more than a lining up of two sets of six.

The method of the metaphysics has two major claims. The first claim is foundational triplication: at the root of any domain there are three concepts, and the other concepts of the domain are built on the three. The second claim is type isomorphism: the pattern of relationships at the basis of each domain corresponds to the pattern at the basis of every other domain, because every domain is constituted by comparison and comparison has one structure. Measurement is a comparison, and interaction is a comparison. So the structural features of measurement must align with the structural features of interaction, and both sets of features must align with the structural features of comparison, and the structural features must align by modality, because modality is what the structure of comparison is made of.

The alignment of this essay consists of two alignments, and the two alignments can be checked independently of each other. In *Comparison* I check comparison against measurement. In this essay I have checked interaction against measurement, using the statement of the six intrinsics of interaction in *An Immanent Metaphysics*. The statement in *An Immanent Metaphysics* was written with the modalities and the rows assigned before any comparison to physics was drawn. The two checks compose: the two correspondences fit together into one correspondence. If the six intrinsics of interaction mapped to the six measures in some order other than the order that the intrinsics of comparison require, the two checks would not compose. The framework would then be in trouble. The two checks, comparison against measurement and interaction against measurement, do

compose. That the two checks compose is evidence of the kind that the metaphysics is able to offer: consistency across independently stated structures, and not experiment.

There is a further sign that the alignment is more than a pattern found by looking for a pattern. Each column of the grid is a content in a context, and each row is governed by one of the two laws. The six measures can be arranged so that every column and every row carries a structural meaning, and six arbitrarily chosen quantities would not allow such an arrangement. Six quantities picked from a physics textbook would not sort into three modal pairs, with the content of each pair governed by symmetry and the context of each pair governed by continuity. The six measures do sort into three modal pairs, with content governed by symmetry and context by continuity. The sorting of the six measures is either a coincidence or a consequence, and I read the sorting as a consequence.

VII. What the Grid Says About the Two Theories

I read the two great theories of physics, general relativity and quantum mechanics, by the columns of the grid. The reading is brief, because the matter belongs to the essay on cross-modal reach in Part III. I take classical mechanics first, because the structure of the grid already shows in classical mechanics.

Newton's second law, $F = ma$ (force equals mass times acceleration), relates three quantities: force, the immanent content; mass, the omniscient content, as inertia; and acceleration, the second rate of change of position in time. The three quantities have different dimensions, physical meanings and procedures of measurement, so the three quantities are distinct. Each of the three quantities, force, mass and acceleration, is measured only through the other two quantities. A force is measured by the acceleration that the force gives a known mass. A mass is measured by the acceleration that a known force gives the mass. An acceleration is measured by comparing positions at three or more times. The law says that the three quant-

ities are related in a way that keeps the three distinct and requires all three, and the law does not say that force equals mass, or that mass equals acceleration. Axiom III says that the immanent, the omniscient and the transcendent are distinct, inseparable and non-interchangeable. So Newton's second law is an instance of Axiom III in mechanics.

The second law also shows the step of Axiom II in which a class of the immanent precedes an instance of the omniscient. Forces act through time (the immanent column). The acceleration of a body is the force on the body divided by the body's mass. Velocity is accumulated acceleration and position is accumulated velocity, so forces acting through an interval of time fix the position of the body at the end of the interval (the omniscient column). The integration of acceleration into velocity and of velocity into position runs from the immanent to the omniscient, as the step of Axiom II does. Newtonian mechanics departs from the precedence of Axiom II on the return from position to force. In Newton's law of gravitation, the configuration of the masses fixes the forces on every body at once, at every distance, with no span of time between the configuration and the forces. The step from configuration to forces runs from the omniscient back to the immanent with no interval of time. Newtonian mechanics uses the Galilean structure of space and time, in which signals may have any speed, so the Galilean structure has no boundary that would supply an interval (*The Gravitational Passage*, Chapter 10, Section III). Newtonian dynamics is a loop, in which forces fix positions through time and positions fix forces at once, so the loop of Newtonian dynamics is a loop of two terms, the immanent and the omniscient, and the transcendent column does not enter the loop. The loop returns from positions to forces instantaneously, and that instantaneous return is the first of the limits that physicists after Newton found (*Measurement*, Chapter 5, Sections II and III).

> **On the Lagrangian and Hamiltonian Formulations**
>
> The Lagrangian formulation of classical mechanics is the same physics reorganized around the principle of stationary action. The principle of stationary action says that a body moves along the path for which a quantity

called the action is stationary. For a body in a potential, the Lagrangian is the difference between the kinetic energy and the potential energy. In the terms of the six measures, the kinetic energy is the energy of motion expressed through momentum, force and time. The potential energy is a relation of pattern in space across possibility (*Measurement*, Chapter 7, Section I). So neither the kinetic energy nor the potential energy is a single measure. The Hamiltonian formulation is the same physics reorganized around phase space, the space of positions and momenta. In phase space a position and its momentum are canonically conjugate. Canonical transformations preserve the symplectic structure of phase space. The symplectic structure belongs, with Galilean invariance, to the symmetric formalism of the theory (*Measurement*, Chapter 8, Table 8.1). The Newtonian, Lagrangian and Hamiltonian formulations are equivalent in their predictions wherever all three apply. Equivalent formulations are interchangeable, and Axiom III requires of a triple that the members of the triple be non-interchangeable, so I do not read the three formulations as a modal triple.

General relativity describes the omniscient column: mass in space, mass and energy in relation to the geometry that mass and energy occupy. General relativity describes the omniscient column by way of the immanent column, force in time, which in general relativity is the dynamics by which curvature and motion answer to one another. General relativity describes the immanent column as continuous. Quantum mechanics describes the transcendent column: probability in possibility, the weighting of outcomes over a space of alternatives. Quantum mechanics describes the transcendent column by way of the same immanent column, as the dynamics of fields and their interactions. Quantum mechanics describes the immanent column as discrete.

The two theories share the middle column, and they do not share it in the same way. General relativity applies continuity to the middle column, and quantum mechanics applies symmetry to the middle column. The overlap of the two theories is where the two survivors of the Incommensuration Theorem are both asked to be perfect at once. The Incommensur-

ation Theorem says that the two survivors cannot both be perfect at once. So the overlap is not a meeting point of the two theories. What would connect the omniscient column to the transcendent column without passing through the immanent column is what a unification would have to be. The first axiom, Axiom I, says that the omniscient and the transcendent are in conjugate relationship to one another, with the immanent more fundamental than either. So the connection of the omniscient and the transcendent runs through the immanent and not directly. The connection through the immanent is the interaction itself, of which all six cells are cells, and not a further formalism.

General relativity colonizes the middle column from the left, from the omniscient side of the grid. In general relativity, time is treated as a geometric dimension, and so the omniscient concept of space is extended into the immanent domain. In general relativity, force is treated as curvature (a geometric, structural property), and so the immanent content is pulled into the omniscient framework of continuous manifold geometry, the geometry of smoothly curved spaces. Quantum mechanics colonizes the middle column from the right, from the transcendent side of the grid. In quantum mechanics, force is treated as the exchange of quantized mediators, particles that carry a force between bodies, and so the immanent content is pulled into the transcendent framework of probabilistic possibility. In quantum mechanics, time is treated as the parameter of deterministic state evolution punctuated by measurement events, and not as a geometric dimension. The quantum concept of time, as a parameter, is different in kind from the geometric concept of time. Neither theory handles the middle column on the middle column's own terms, which are the terms of the immanent: each theory assimilates the middle column into the theory's own modal framework. One should expect from the axioms that each theory assimilates the middle column in that way. By Axiom I the immanent is more fundamental than the omniscient and/or the transcendent, so the immanent is derived from neither. So in every formalism that contains the immanent, the immanent is taken as given, without derivation. In general relativity, the findings are taken as events of the mani-

fold. In quantum mechanics, the findings are joined to the formalism by a rule stated beside the unitary evolution, the continuous evolution of the quantum state (*The Unquantized Arena*, Chapter 10, Proposition 10.3). The middle column resists ownership by either side: the immanent is derived from neither the omniscient nor the transcendent. The disagreement between general relativity and quantum mechanics is the physical expression of that resistance to ownership.

In this section I have given my reading of general relativity and quantum mechanics by the columns of the grid. I state the reading more carefully, with its literature, later in this volume. I put the reading in this essay only so that the reader sees that the grid has consequences beyond classification.

VIII. Summary

Four of the claims I make in this essay are claims of the metaphysics itself. The first claim is that any measurement involves six intrinsics. The second claim is that the six intrinsics arrange into three modal columns and two rows. The third claim is that the content row is governed by symmetry law and the context row by continuity law. The fourth claim is that content must be quantized and context continuous at the two absolute scales of a domain. I argue the correspondence of the six measures with the six intrinsics of comparison in *Comparison; The Necessary Basis*, Chapter 8. I read the two great theories by column, and the reading is a reading of known physics. The grid is a structure of kinds. The grid says nothing about magnitudes.

Any measurement involves six intrinsics: mass, space, force, time, probability, possibility. The six measures arrange into three modal columns, each column a content in a context, and into two rows, the content row governed by symmetry and the context row governed by continuity.

The six measures are the six intrinsics of comparison read through two descriptions. Comparison, taken as an event, is interaction, and interaction has six intrinsics of its own: distinction, fixed characteristic, irreversibility, direction, transformation, specification. Interaction taken under a description is measurement, and the six intrinsics of interaction correspond one to one with the six measures, column for column and row for row. So the chain of correspondences from comparison to physics closes.

The Incommensuration Theorem then says what the two rows must be at their limits. Content, which is symmetric, must be discontinuous at the microscopic edge of any domain: content must be quantized there. Context, which is continuous, must be asymmetric at the macroscopic edge: context must be unbroken and directed. The two rows are the two survivors of the Incommensuration Theorem, and in no single theory are both survivors found perfected. Only the interaction finds both survivors perfected, by being the event in which all six measures occur and not by describing the two survivors.

KEY CONCEPTS IN THIS ESSAY

- **The six measures**: mass, space, force, time, probability, possibility; the six intrinsics that any concept of an event of measurement involves, at least implicitly; three roles taken twice, as content and as context (*Comparison*, Chapter 8).
- **Mass**: used with the combined meanings of inertia, pattern, form, shape, and structure; the content of the omniscient column.
- **The six intrinsics of interaction**: distinction of subject and object, fixed characteristic of the object, irreversibility of change, direction of flow, transformation of information, specification of transformation attributes; the middle term between comparison and measurement.
- **The grid**: three modal columns (mass in space, force in time, probability in possibility) crossed with two rows (content and context); every measurement occupies all six cells.

- **Content triaxial and context triaxial**: the class concept of physical content composed of mass, force, and probability; the class concept of physical context composed of space, time, and possibility.
- **Columns of causality, change, and choice**: the omniscient intrinsics are defined in terms of causality, the immanent in terms of change, the transcendent in terms of choice.
- **Row law**: content measures are defined by symmetry law; context measures are defined by continuity law.
- **Quantization of content**: at the absolute microscopic scale of a domain, pattern, force, and probability must be symmetric and discontinuous; discontinuity is isomorphic with quantization.
- **Continuity of context**: at the absolute macroscopic scale of a domain, space, time, and possibility must be continuous and asymmetric; non-quantized.
- **Physical face**: the six measures are the six intrinsics of comparison read through two descriptions, comparison as interaction and interaction as measurement.

Materials Reviewed

Landry, Forrest. *Comparison; The Necessary Basis.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-062-6. Chapter 8 (the six measures and the six intrinsics); Chapter 5, Section VIII (the count of six).

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.85-8 to 1.85-13, 1.85-15, 1.85-16 (the six intrinsics of measurement; content and context triaxials; symmetry law and continuity law; quantization at the microscopic scale and continuity at the macroscopic; the modal rows; the correspondence with the intrinsics of interaction); 1.85-3, 1.85-4, 1.85-5 (the six intrinsics of interaction; causality, change, and choice; perception and expression); 1.43-6 (measurement as interaction); 1.3-1 (the three axioms).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six measures.

Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3. Chapter 3, Section II (Axiom I).

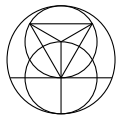
Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapter 3, Section II (force and pattern in the grid); Chapter 5, Sections II and III (the limits physics found); Chapter 7, Sections I and II (energy in the six measures; the chain of the defining constants); Chapter 8, Table 8.1 (the symmetric formalism).

Landry, Forrest. *The Gravitational Passage; Deriving General Relativity from the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-056-5. Chapter 10, Section III (the order of precedence).

Landry, Forrest. *The Unquantized Arena; A Structural Diagnosis of Quantum Gravity and the Measurement Problem.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-067-1. Chapter 10, Proposition 10.3.

PART II

Known Results as Instances



Essay 5

Bell's Theorem as an Instance of the Incommensuration Theorem

Why Lawfulness and Locality
Cannot Both Be Absolute

ABSTRACT

In 1964 the physicist John Bell proved a theorem about pairs of particles that are prepared together and then separated. Bell's theorem establishes that no local hidden-variables theory can reproduce all the predictions of quantum mechanics, and the experiments that followed Bell's theorem have confirmed that nature behaves as those predictions say. In this essay I argue that Bell's result is an instance of the Incommensuration Theorem, and that the two theorems correspond directly, term for term. Lawfulness is the assumption that physical law is the same in every place and time, and lawfulness is a special case of symmetry, which is sameness of content across difference of context. Locality is the assumption that no influence crosses a distance in zero time, and locality is a special case of continuity: no change of content without a corresponding change of context. The Incommensuration Theorem says that symmetry and continuity cannot both be applied absolutely and together. Bell's dichotomy is the statement that reality cannot be both local and realistic, and I recover Bell's dichotomy as the form that the general limit of the Incommensuration Theorem takes in the domain of quantum correlation. I then state Bell's result as a trilemma, a set of three properties of which at most two can be kept: the universality of causation, the consistency of law, and locality. I explain

why I give up the universality of causation rather than locality. The correlations Bell studied are real but they are not signals, and only the assumption that every change must be causal turns a correlation into an influence. Hidden variables cannot restore causation once causation has failed. Superdeterminism is the attempt to keep all three properties at once, and superdeterminism is the conjunction that the Incommensuration Theorem forbids. I close with what Bell's result means for the limits of the scientific method itself: science can establish causal knowledge, and science cannot establish the absolute truth of either the symmetry or the continuity on which science relies.

Note on framework. This essay depends on the Introduction to this volume for four things: the six intrinsics, the four secondary compounds, the full statement of the Incommensuration Theorem, and the fixed modal alignment. This essay also depends on two essays in Part I: the essay on the two types of law, and the essay on determinism and causality. I continue the argument of this essay in two later essays: the essay on hard randomness, which immediately follows, and the essay on the structural impossibility of superdeterminism in Part III. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Bell's Theorem Stated

Bell's theorem concerns the correlations between measurements made on pairs of particles that were prepared together and then separated. In this essay a correlation is a regular agreement or disagreement between the results found at the two particles. Bell asked a precise question about the correlations that quantum mechanics predicts. Could the predicted correlations be accounted for by a theory in which each particle carries, from the moment of preparation, definite properties that fix what any measurement will find, and in which the measurement made on one particle has no instantaneous effect on the other particle?

Physicists call a theory with both features, definite properties fixed in advance and no instantaneous effect, a local hidden-variables theory. A local hidden-variables theory makes two assumptions. The first assumption is realism: each particle has definite properties before any measurement, and the properties are fixed by variables that we may not know but that exist all the same. The second assumption is locality: what is done to one particle does not instantaneously change what will be found at the other particle. Bell gave a mathematical proof that is complete within its own formalism. Bell's proof shows that any theory making both assumptions must satisfy a certain inequality in the statistics of the correlations, an upper limit on how strong the correlations can be. Quantum mechanics predicts that the inequality is violated, and experiments confirm that the inequality is violated. The experiments began in earnest in 1982 with the work of the physicist Alain Aspect and his collaborators, and the experiments continued through the loophole-closing tests of the last decade, which removed every causal channel by which a violation might have been explained. So at least one of the two assumptions must be given up. Physicists give the standard summary in one line: reality cannot be both local and realistic.

I state my claim exactly at the outset, because the title of this essay could otherwise be read as a larger claim than mine. I do not derive Bell's inequality again in this essay, and I do not offer another route to Bell's inequality. Bell's argument is rigorous within its own formalism, and the formalism of Bell's argument is quantum mechanics. I offer a reading of Bell's result: an account of why realism and locality turn out to be incompatible. My account does not depend on the formalism of quantum mechanics, and I will argue that my account applies to comparison as such, that is, to every act of comparing, whatever is compared. The theorem of physics is Bell's. I make a further claim of my own: Bell's theorem is an instance of something more general, and the rest of this essay is my argument for that claim.

II. Lawfulness as Symmetry

I begin with two assumptions: the assumption of realism, and the assumption that science in general makes in taking the world to be lawful.

Science has an inherent assumption: where the conditions are similar, a physical procedure performed in one place and time gives the same results as the same procedure performed in other places and times. The assumption makes an experiment repeatable, and repeatability makes an observation scientific. The assumption has two parts. The first part is a sameness of content: the results are the same. The second part is a difference of context: the places and times differ. Content is what is compared, and context is the frame within which the comparison is made. In a repeated experiment the content is the result of the procedure, and the context is the place and time of the procedure. The Introduction calls sameness of content across difference of context symmetry. So the repeatability of experiment is symmetry assumed in advance.

The assumption of symmetry goes deeper than the method of experiment. Science regards the essential dynamics of physical process as the same everywhere in the universe. Physicists treat the laws of physical process as invariant under transformations of time and position, that is, under shifts of when and where. At every level, the mathematical expression of the laws of nature rests on notions of symmetry. The conservation of energy and momentum is a symmetry law. I develop the point that conservation is a symmetry law in the essay on the two types of law, in Part I, with Noether's theorem as the instance: the mathematician Emmy Noether proved that each continuous symmetry of a physical law is paired with a conserved quantity. The theories of relativity are built on a sameness of relationship under change of position and motion. Within science, the ultimate assertion of symmetry is that the same physical laws apply everywhere in the universe, with the laws as the content and the universe as the

context. So when scientists regard the universe as lawful, they assert a fundamental symmetry. Lawfulness is symmetry applied to the physical domain.

Bell's first assumption, realism, has the form of lawfulness too. Realism says that a particle has definite properties before measurement, and so realism says that the structural state of the particle fixes the content of the measurement, which is the measurement's outcome. The structural state of the particle is a definite pattern, a law. Under realism, the structural state fixes the outcome whatever the context of the measurement: whatever the setting of the apparatus, whoever performs the measurement, and wherever and whenever the measurement is made. An outcome fixed regardless of its context is sameness of content across difference of context. So realism, in Bell's sense, is lawfulness applied at the scale of the single particle, and realism is symmetry.

III. Locality as Continuity

In this section I show that locality is a special case of continuity.

As physicists use the notion, locality is the claim that no physical influence, interaction or signal can travel faster than light. Locality says that physical process involves no instantaneous passage across space: no jump in zero time between points that are any distance apart. If an interaction spans any distance, the interaction must also span some duration greater than zero. An infinitesimal change in the spatial context produces at most an infinitesimal change in the temporal context of the interaction. Under locality there are no jumps.

I now look at the form of locality, as I looked at the form of realism. The measures of time and space are measures of context: in the essay on the six measures, in Part I, I place time and space in the row of context. Interaction and substance are content within the context of time and space. So when locality says that no signal can cross any distance instantaneously, locality says that every small change in the content (a process, an

interaction, a signal) must come with a corresponding small change in the context (in time and in space). When there is no discontinuity between the change in content and the change in context, sameness of content within sameness of context is continuity. Locality says that there are no abrupt, instantaneous changes, and so locality is a special case of continuity. Locality is continuity applied to the physical domain.

Absolute locality has a further consequence that matters for the rest of this essay. Absolute locality is locality asserted without exception, and to assert absolute locality is to require total continuity of interaction at all scales, down to and including the microscopic scale of zero distance and zero duration. To assert absolute locality is also to require that continuous local dynamics can fully specify all physical process. Absolute locality is therefore not a modest assumption. Absolute locality is the demand that the world be a continuously specified process at every scale, and in the essay on determinism, in Part I, I found that this same demand is unreachable.

Physicists now state Bell's premises as three: local causality, realism, and measurement independence. Local causality is the premise that what is found at one place depends only on what happens nearby, and measurement independence is the premise that the settings chosen for the detectors do not depend on any hidden state of the particles. When I read the three premises with care, I find that they sort into the two demands of Sections II and III: lawfulness and locality. Realism is lawfulness, which is symmetry. Local causality and measurement independence both belong with locality, which is continuity: each of the two premises requires that what is found at one place not depend on what is set at another place, far away (*Incommensuration*, Chapter 15). So my reading holds for the refined, three-premise statement of Bell's theorem as it holds for the classic, two-premise statement.

IV. The Structural Reading

I state the Incommensuration Theorem in full in the Introduction. The Incommensuration Theorem concerns the four secondary compounds of comparison: continuity, discontinuity, symmetry and asymmetry. When two of the compounds are applied absolutely and together, two conjunctions are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two conjunctions survive as valid absolute conjunctions: continuity with asymmetry, and symmetry with discontinuity. To be applied absolutely is to hold exactly, at the foundation of a description. The qualifier "applied absolutely" matters, and I never drop it. Within any finite domain, symmetry and continuity occur together to a finite degree. Symmetry and continuity cannot both be perfected at once.

Now I set the two readings of Sections II and III beside the Incommensuration Theorem. Lawfulness is symmetry. Locality is continuity. A local hidden-variables theory asserts realism and locality together and without qualification, and so the theory asserts symmetry and continuity together and absolutely, which is the first of the two forbidden conjunctions. The Incommensuration Theorem says that no comparison can support the conjunction of symmetry with continuity, applied absolutely. Bell's theorem says that no theory consistent with quantum correlations can support the conjunction of realism and locality, and realism and locality are symmetry and continuity. The two results have the same shape because, on my reading, both results follow from the structure of comparison itself.

One step in the argument of this essay needs to be made explicit, because at that step the argument depends on the metaphysics, the account of comparison on which this book rests. The Incommensuration Theorem forbids the conjunction of symmetry with continuity when the two compounds are applied to the same identity, one and the same thing, in the immanent modality, the modality of interaction, process and reality. A theory of reality is a theory of being, and a theory of reality must be for-

mulated from an immanent basis, not an omniscient one, because reality is immanent in the alignment that I hold fixed throughout this book. In the fixed alignment, existence is omniscient, objectivity transcendent, and reality immanent. The Introduction sets out the three modalities: the omniscient is the mode of structure, the immanent is the mode of process, and the transcendent is the mode of the generative. I state why the immanent basis is not optional in the first axiom of my book *An Immanent Metaphysics*:

Axiom I: The immanent is more fundamental than the omniscient and/or the transcendent. The omniscient and the transcendent are in conjugate relationship to one another.

In the fixed alignment, symmetry is omniscient, continuity is transcendent, and interaction is immanent. Lawfulness is symmetry and locality is continuity, so by Axiom I lawfulness and locality are conjugates, as the omniscient and the transcendent are. The perfected conjunction of lawfulness and locality cannot be found in the immanent, and a theory of reality has to be formulated in the immanent. So the notion that reality is absolutely lawful contradicts the notion that reality is absolutely local.

A conception of reality must therefore allow one of two things. Either the conception allows multiple, mutually inconsistent sets of physical laws, applicable in different places and times, which is a failure of lawfulness and of symmetry. Or the conception allows inherently non-local interactions and changes, which are non-deterministic at root: a failure of locality and of continuity. No theory of reality can assert both total generality and total determinism. Within physics, Bell's theorem establishes the impossibility of asserting both total generality and total determinism. Reality can be completely lawful and somewhat non-local, or completely local and somewhat non-lawful. Reality cannot be both absolutely lawful and absolutely local. The Incommensuration Theorem is the theorem of the metaphysics, and the Incommensuration Theorem predicts the form of Bell's result from structural premises alone, without reference to the con-

tent of physical theory. Bell found his result in quantum correlations. The Incommensuration Theorem says that Bell's result had to be found somewhere.

> **The Correspondence**
>
> Realism is the definiteness of a particle's properties independent of the context of measurement, and realism corresponds to symmetry. Locality is the absence of instantaneous influence, and locality corresponds to continuity. The violation of Bell's inequality corresponds to the impossibility of the absolute conjunction of symmetry and continuity. Two options remain open after Bell's result: lawful but non-local, and local but non-lawful. The two options correspond to the two survivors of the Incommensuration Theorem, symmetry with discontinuity and continuity with asymmetry. The general result, the Incommensuration Theorem, does not depend on quantum mechanics. The specific result, Bell's theorem, does depend on quantum mechanics. The structural reason for the limit is the same in both results.

V. Bell's Dichotomy as a Special Case

The Incommensuration Theorem does more than forbid two conjunctions. The Incommensuration Theorem also says which two conjunctions survive, and the two survivors are the two options that remain open after Bell's result.

The first survivor is symmetry with discontinuity: completely lawful, somewhat non-local. On the first option the laws of physics are universal, and universality is symmetry. But locality fails at some scale, and the failure of locality is a discontinuity. Physicists who take the first option read quantum correlations as an instantaneous influence: the measurement on one particle affects the correlations seen at the other particle. The laws are

preserved, and locality is not. Most physicists have taken the first option in describing what the violation of the inequality means, and the first option is what Albert Einstein's phrase "spooky action at a distance" names.

The second survivor is continuity with asymmetry: completely local, somewhat non-lawful. On the second option all interactions are local, and locality is continuity. But the laws that govern outcomes depend on context, and dependence on context is asymmetry. The outcome depends on the specific measurement performed, the specific apparatus, the specific moment. No specification of the particle's state is independent of the context of the particle's measurement. In most interpretations of quantum mechanics the measurement outcome cannot be fixed independently of the measurement context, and so in practice those interpretations adopt the second option, whether or not their authors say so.

So I recover Bell's dichotomy, local or realistic but not both, as a special case of the Incommensuration Theorem. The general structure has four compounds and two survivors. In the domain of quantum correlation, the four compounds appear as lawfulness, the failure of lawfulness, locality and the failure of locality, and the two survivors appear as Bell's two options. Nothing in the quantum formalism is needed to see that there must be exactly two options, or to see which two options they are. The quantum formalism supplies one thing, and only the formalism can supply it: the finding that nature actually violates the inequality, rather than merely being permitted to violate the inequality.

VI. The Trilemma, and Which Horn to Give Up

I now state Bell's result a second way, because the second way shows a choice that the first way hides.

The CAP theorem is a well-known result in distributed computing, the study of computer systems spread over many connected machines. Eric Brewer, a computer scientist, stated the CAP theorem in 2000, and the computer scientists Seth Gilbert and Nancy Lynch proved it in 2002. The

CAP theorem says that a replicated data store, which keeps copies of the same data on several machines, cannot guarantee three properties at once: consistency (every read returns the most recent write), availability (every request receives a response), and tolerance of partitions in the network (the store keeps working when the network splits into parts that cannot reach one another). Bell's theorem can be read as a trilemma of the same form as the CAP theorem: of three properties, at most two can be kept. The first property is the universality of causation: every change in the world is accounted for by causal process, and only by causal process. The second property is the consistency of causation, which I also call the consistency of law: wherever the causal laws apply, the causal laws are the same type of law everywhere. The third property is locality: all causal process is local, bounded by the speed of light. When Bell's result is read as a trilemma, Bell's result says that at most two of the three properties, the universality of causation, the consistency of causation and locality, can be kept.

When the physics community faced Bell's result, the community kept the first two properties and gave up the third. The reasons of the physicists were not foolish. If the same causation does not apply everywhere, then the idea of knowing the causation that holds in general throughout the universe fails. Then a second idea fails too: the idea of what it means to be scientific, which is to be able to say that we have found a lawfulness, that we can describe the lawfulness causally, and that the lawfulness is therefore understandable and can be treated as explanation. The idea of being scientific depends on the concept of causation at every step: finding a lawfulness, describing the lawfulness causally, treating the lawfulness as explanation. The physicists gave up locality to keep the concept of causation, and they live with an influence that has no speed and no mechanism. Bell's result was very hard to accept, because Bell's result challenged an underlying ideology: the perfect notion of causation, perfectly applied. People want perfection in their theories, of generality or of specification, and Bell's result required that one of the two perfections be surrendered. But which perfection to surrender was a choice, and is still a choice.

I describe the choice of what to give up more exactly. I keep the consistency of causation where causation applies, and I keep locality as physics keeps locality, in the form of no signaling: no signal crosses a distance in zero time. I give up the universality of causation. Giving up the universality of causation leaves a gap in the coverage of law, and such a gap is a discontinuity. Keeping the consistency of law is keeping symmetry. So my resolution is symmetry with discontinuity: the survivor that physics also took (*Incommensuration*, Chapter 15), described without the word "nonlocal". I now give the reason carefully.

To produce the correlations that Bell studied, two particles are prepared together and sent to detectors far apart. Each detector is set to ask its particle one question, chosen by the detector's orientation, and records an answer of yes or no. When the two detectors happen to ask the same question, the answers always agree or always disagree, depending on how the pair was prepared. When the two detectors ask perpendicular questions (questions set at right angles), the agreement is random. The record at each detector, taken alone, is a random sequence. The correlation appears only when the two records are brought together afterward, by ordinary means and at ordinary speed. The correlation cannot be used to send anything. No choice made at one end changes the statistics recorded at the other end. The experimenter controls only the question asked, never the answer. An experimenter could try to fix the answer in advance by measuring the particle before the particle reaches the detector, but the earlier measurement destroys the entanglement, the shared quantum state of the pair, on which the correlation depends. Nothing crosses the distance between the detectors, and so there is no signal. The correlation is observed after the fact, as having happened, and the correlation is not an influence travelling from one place to the other.

What, then, has Bell's result violated? Bell's result has not violated locality in the sense of no signaling, which physics also holds: no signal, influence or interaction crosses a distance in zero time. In the Bell experiments no signal crosses a distance in zero time. Bell's result has violated the expectation that a correlation as strong as the measured one must

have a causal account, either in the shared past of the two particles or in an influence between the two particles. Bell's theorem shows that neither causal account is available. There are more correlations in nature than any coherent notion of causality can explain. The correlations are non-causal in the strict sense of the word: the correlations have no causal explanation.

Physicists who take the mainstream option read a non-causal correlation as a non-local cause, and they do so because of an assumption made in advance: every change is causal, and there is no such thing as change that is not causation. If every change is causal, the correlation must be an influence, and since the influence cannot be local, locality must be given up. Without the assumption that every change is causal, locality does not need to be given up. Instead the universality of causation must be given up: there is change in the world that causation does not account for. The metaphysics has a name for change that is not causation. The name is choice, in the general sense that I give the word in *An Immanent Metaphysics*: choice is the emergence of the new. Change is the superclass of both causation and choice. In the modal alignment, causality is omniscient, choice is transcendent, and change is immanent. Some aspects of change are accounted for by causal knowledge, and other aspects are not, and the residue, the part of change that causal knowledge does not account for, is real. I develop what the residue is in the essay on hard randomness, which follows this essay.

I keep locality and give up the universality of causation for the following reason. As physics takes locality, locality says that nothing is compared across the boundary of comparison: no signal crosses a distance in zero time. So locality is a statement about the edge of the domain of comparison, and the correlations satisfy the statement, because no signal crosses the edge. The universality of causation is the demand that every change be pattern, and pattern is omniscient. Change occurs in the act, and under Axiom I the act comes before the pattern, because the immanent is more fundamental than the omniscient. When locality and the universality of causation conflict, I keep the boundary of comparison and give up the claim that all change is causal. In the words physicists use, the

correlations are non-local, and the correlations are confined inside a constraint of no signaling. In the words of this essay, the correlations are not causal, and the correlations carry nothing from one detector to the other.

VII. Hidden Variables and the Superdeterministic Escape

I now reply directly to two attempts to keep all three properties of the trilemma at once.

The first attempt is hidden variables. The idea of hidden variables was that something in the source of the particles, some definite state that we do not know, might account for the correlations: the two particles carry, from their common origin, the answers that they will later give. The hidden-variables idea is the shared-past account, in which an event A gives rise to events B and C, and B and C are then correlated because both descend from A. Bell's inequality is precisely the bound on how much correlation a shared past can supply, and the measured correlations exceed the bound. A deeper point lies beneath the arithmetic of the bound. Physicists hypothesized hidden variables to be the basis of the causation that produces the outcomes. But once the observed correlations have exceeded what any causal account allows, what the hidden variables are no longer matters. A variable cannot restore causation after causation has been violated. The local hidden-variables program was a temporary attempt to account for Bell's result causally, and the program failed, which is what the summary "no local hidden variables" records.

Two deterministic accounts remain open to a determinist. In the pilot-wave theory of the physicist David Bohm, the particles keep hidden positions and locality is given up: the outcome in one laboratory depends on the setting in the other laboratory (Bohm, 1952). In superdeterminism the experimenters' settings are fixed together with the particles' states, so the independence of the settings, on which every experiment relies, is given up. The Bell experiments constrain both accounts, and the Bell experiments do not logically exclude either account. As accounts of a whole

world, both accounts are excluded by the Incommensuration Theorem. A whole world completely fixed by one law perfects symmetry and continuity together, and the Incommensuration Theorem forbids that pairing. Superdeterminism adds to the forbidden pairing the collapse of choice into causation, in which whatever the causal pattern does not explain is declared to be a case of the pattern not yet understood. But choice and causation are distinct, and neither can be substituted for the other. A deterministic formalism, such as Bohm's, remains available as a description. The findings of a deterministic formalism carry the statistics of quantum mechanics, and no finding shows that the formalism is deterministic.

The second attempt is superdeterminism. Superdeterminists try to keep both lawfulness and locality by asserting that the settings of the detectors and the states of the particles share a common deterministic ancestry: the experimenter's choice of question was fixed, together with the particle's answer, in a past that determined both. On the superdeterministic account, the correlation is a shared determination of everything at every scale, the choices of the experimenters included, and the correlation is neither an influence nor a shared hidden state of the particles alone.

Where superdeterminism is read in terms of the structure of comparison, superdeterminism is the attempt to maintain both symmetry and continuity at once, absolutely. Superdeterminists keep lawfulness by making law universal, down to the choice of what to measure. Superdeterminists keep locality by making every process continuous, with no gap between the past and any outcome. So superdeterminism is determinism extended to the observers. Superdeterminism is therefore excluded by the argument of the essay on determinism before any test is made in the laboratory, because the conjunction that superdeterminism requires is the conjunction that the Incommensuration Theorem forbids. Bell's theorem and the Incommensuration Theorem agree on one point: the superdeterministic escape is not available. I develop the exclusion of superdeterminism in full in the essay on the structural impossibility of superdeterminism, in Part III, including the category error on which the superdeterministic position depends: the error of collapsing choice into causation, treating a thing of

one kind as a thing of another kind. In this essay I add only one point. Superdeterminism is the demand to have all three horns of the trilemma, all three of its properties, and not a further option. Exactly that demand is impossible, because at most two of the three properties can be kept.

VIII. The Limits of the Scientific Method

I read lawfulness as symmetry and locality as continuity, and the reading has a consequence for science itself that goes beyond Bell's theorem.

Scientists can use the scientific method to make observations about causality. By the scientific method, scientists can establish that similar conditions yield similar results, that regularities hold, and that patterns repeat. Knowledge that similar conditions yield similar results is causal knowledge, and causal knowledge is what the method is for. But even in principle, no one can use the scientific method to make a direct observation about continuity or locality. An experimenter can observe that in one case there was no jump, and no experimenter can observe that there are no jumps at all. Nor can anyone use the scientific method to make a direct observation about symmetry, even though scientists must assume symmetry in their practice, because the assumption that a result will repeat is what allows the result to count. No experiment could validate the absolute and universal truth of continuity, the claim that all interaction and change is local, or of symmetry, the claim that reality is lawful everywhere and always, and no finite collection of experiments could validate either truth. Science has six theoretical presuppositions: material monism (the view that only matter is real), causal determinism, locality, strong objectivity (the view that what is real is independent of every observer), universality, and epiphenomenalism (the view that mind has no effect on matter). Each of the six presuppositions is challenged by developments within science itself, and the challenges cannot be resolved from within the scientific framework.

I am stating the limit of what the scientific method can establish, and I am not making a complaint about the scientific method. Where an aspect of the physical world is real and yet inherently not repeatable, observable no more than once, that aspect would be non-lawful and non-symmetric in time and space, and therefore outside the scope of study available to the method of science. Bell's theorem is one place where physicists, using the scientific method, came to the edge of what they could explain by the method, and the physicists reported what they found there: a correlation that they could observe and could not explain. I hold that anyone using the scientific method must come to the edge of what can be explained by the method, because the method rests on symmetry, and perfected symmetry cannot be had in the domain where the method is used. Science can establish causal knowledge. Because of how science is built, science cannot establish the deterministic, the fully symmetric or the fully continuous.

IX. Summary

The central claim of this essay is that Bell's theorem is an instance of the Incommensuration Theorem. The central claim is a reading of a known result: the reading gives the structural reason that Bell's result is true, and says that the reason is not confined to the quantum formalism. I recover Bell's dichotomy as the two survivors of the Incommensuration Theorem, and the recovery is also a reading of a known result. In my account of the correlations I keep no signaling and give up the universality of causation. My account of the correlations is grounded in the metaphysics, and my account describes the survivor that physics took, symmetry with discontinuity.

Bell's theorem is an instance of the Incommensuration Theorem.

Lawfulness is symmetry. Locality is continuity. The Incommensuration Theorem states that symmetry and continuity cannot both be perfected in the same comparison. Bell shows that lawfulness and locality cannot both

be maintained in the face of quantum correlations. The general limit of the Incommensuration Theorem contains the specific limit of Bell's theorem as one of its cases. The two options Bell leaves open are the two conjunctions that the Incommensuration Theorem allows.

Absolute lawfulness and absolute locality cannot hold together, and the impossibility is a feature of comparison itself, neither peculiar to quantum mechanics nor an artifact of the formalism Bell used. The limit holds in any domain where both universal invariance of law and complete continuity of interaction are demanded. Bell came up against the limit in the correlations of separated particles. The Incommensuration Theorem says that the limit is there to be found in every domain.

No theory of reality can assert both total generality and total determinism. A physicist may respond in one of two ways. The first way is to keep the universality of causation and give up locality, which is what most of physics has done. The second way is to keep locality, keep the consistency of law where law applies, and give up the claim that all change is causal. I take the second way, because the correlations are real but they are not signals, and because reality is where signals travel. Either way, the scientific method is built on the assumption of symmetry, and no one can use the method to validate the assumption of symmetry absolutely, nor the assumption of continuity on which the method also relies. Science establishes causal knowledge. The incompatibility of lawfulness and locality follows necessarily from the structure of comparison, and is not something peculiar to the quantum world.

KEY CONCEPTS IN THIS ESSAY

- **Lawfulness**: the assumption that the same physical laws apply in every place and time; a special case of symmetry, sameness of content across difference of context; assumed by science through its dependence on repeatable observation.

- **Locality**: the assumption that no influence, interaction, or signal crosses a distance in zero time; a special case of continuity, no change of content without a corresponding change of context; time and space are contextual measures, interaction is content within them.
- **Realism**: Bell's first assumption, that a particle has definite properties prior to and independent of measurement; lawfulness at the scale of the single particle; symmetry.
- **Bell's theorem**: no local hidden-variables theory reproduces all the predictions of quantum mechanics; the conjunction of realism and locality fails; a theorem of physics whose inequality I do not derive again in this essay.
- **Instance relationship**: Bell's result is the specific form the Incommensuration Theorem takes in the domain of quantum correlation; the general limit does not depend on the quantum formalism, the specific one does.
- **The two survivors**: symmetry with discontinuity, read as completely lawful and somewhat non-local; continuity with asymmetry, read as completely local and somewhat non-lawful; Bell's dichotomy as a special case.
- **The trilemma**: universality of causation, consistency of causation, locality; at most two of the three can be kept; mainstream physics keeps the first two, and I keep the last two.
- **Non-causal correlation**: agreement between separated records that exceeds any causal account, cannot be used to signal, and leaves the statistics at each end independent of the setting at the other; real, but not an influence.
- **Hidden variables**: the hypothesis that a shared definite state at the source accounts for the correlations; a variable cannot restore causation once causation has been exceeded.
- **Superdeterminism**: the attempt to keep lawfulness and locality by determining the experimenters' choices along with the particles' states; the demand for all three horns; the forbidden conjunction; excluded.

- **Limits of the scientific method**: science establishes causal knowledge; science cannot validate the absolute truth of either symmetry or continuity, though science must assume symmetry in its practice.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.83-1, 1.75-13 (the two laws); 1.85-4 (causality, change, and choice); the section Law and Locality of the appendix on the Incommensuration Theorem.

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The essay on the universal law.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Aspect, Alain, Philippe Grangier, and Gérard Roger. "Experimental Realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A New Violation of Bell's Inequalities." *Physical Review Letters* 49, no. 2 (1982): 91–94.

Aspect, Alain, Jean Dalibard, and Gérard Roger. "Experimental Test of Bell's Inequalities Using Time-Varying Analyzers." *Physical Review Letters* 49, no. 25 (1982): 1804–1807.

Hensen, B., et al. "Loophole-free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres." *Nature* 526 (2015): 682–686.

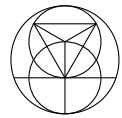
Giustina, Marissa, et al. "Significant-Loophole-Free Test of Bell's Theorem with Entangled Photons." *Physical Review Letters* 115 (2015): 250401.

Shalm, Lynden K., et al. "Strong Loophole-Free Test of Local Realism." *Physical Review Letters* 115 (2015): 250402.

Bohm, David. "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables, I and II." *Physical Review* 85 (1952): 166–193.

Brewer, Eric A. "Towards Robust Distributed Systems." Keynote address, ACM Symposium on Principles of Distributed Computing, Portland, Oregon, 2000.

Gilbert, Seth, and Nancy Lynch. "Brewer's Conjecture and the Feasibility of Consistent, Available, Partition-Tolerant Web Services." *ACM SIGACT News* 33, no. 2 (2002): 51–59.



Essay 6

Hard Randomness

The Incompressible Residue
and the Microscopic Boundary of the Domain

ABSTRACT

In this book, hard randomness is the name for that part of what happens which no causal knowledge could have predicted, not for want of instruments or theory, but because there is nothing prior from which a prediction could have been made. In this essay I develop the concept of hard randomness from first principles. I distinguish hard randomness from soft randomness, the randomness that comes from ignorance. I place hard randomness against a spectrum of concepts: the two ends of the spectrum are determinism and pure randomness, and both ends are abstractions that lie beyond the domain of comparison, the range of everything that can be compared. I show that hard randomness is what comes into the domain through the end opposite determinism. I also show why causation and choice lie between the two ends. I then read three results of physics together: Bell's theorem, Heisenberg's uncertainty principle, and the microscopic limit that Planck's constant marks. I read the three results as jointly establishing that the concept of hard randomness cannot be factored out of any account of nature that is meant to agree with experiment. The loophole-closing tests of Bell's inequality are the experiments that removed every causal channel by which correlations that violate the inequality might have been explained, and the tests leave two options standing: superdeterminism or hard randomness. I argue

that Occam's razor is enough to decide between the two options before the structural argument against superdeterminism is even brought to bear. I read atomic decay and the three-body problem as instances of hard randomness. The three-body problem is an instance because the motion of three bodies amplifies differences in the exact state of the system (its microstate), differences that lie below the limit of measurement. I then argue that the microscopic limit is a categorical boundary of the domain of comparison and not a practical one, that hard randomness is what anything arriving through that boundary must look like from inside the domain, and that nothing can be assumed about what lies beyond the boundary. I close by placing hard randomness within the triple of choice, change, and causality, and by pointing to the binding of hard randomness with subjectivity and the arrow of time, which I set out in *Accessing the Real* and derive from the Incommensuration Theorem in *Incommensuration*.

Note on framework. This essay depends on the Introduction to this volume for the Incommensuration Theorem and the modal alignment, on the essay on determinism and causality in Part I, and on the essay on Bell's theorem immediately preceding. The Introduction fixes the modal alignment: symmetry is assigned to the omniscient modality, continuity to the transcendent modality, and interaction to the immanent modality. I refer in this essay to the essay on the binding of subjectivity, temporal direction, and hard randomness in *Accessing the Real*, and I point forward to the essays on superdeterminism in Part III and on the microscopic boundary in Part IV. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. What "Hard" Means

The word "random" can mean two things, and everything I argue in this essay depends on keeping the two meanings apart.

In the first sense, a thing is random when we cannot predict it. The toss of a coin is random in this sense. So are the weather next month, the next digit of a long decimal we have not computed, and the card at the top of a shuffled deck. In each case there is, or might be, a fact of the matter that fixes the outcome in advance. We simply do not have access to that fact. Better instruments, more computation, or a fuller theory would in principle reduce the randomness, perhaps to nothing. Randomness in the first sense is soft randomness, and soft randomness is a statement about our knowledge.

In the second sense, a thing is random when there is nothing from which the thing could have been predicted. No causal knowledge, however complete, would have yielded the outcome, because the outcome was not contained in anything prior. Better instruments do not help, because there is nothing for the instruments to find. I call the part of what happens that is left unpredicted the residue. A fuller theory does not help either, because the residue is a feature of what the theory is about. The residue is not a gap in the theory. Randomness in the second sense is hard randomness, and hard randomness is a statement about the world.

The word "hard" is doing specific work. The word says that there is no possibility, not now and not ever, of reducing the residue to causal knowledge or to any kind of logical predictability. In the hard sense, random is what remains when a thing cannot be made causal at all, even in principle. If any notion of causality could be brought to bear on the thing, the thing would not be random. Hard randomness is the incompressible residue: what is left over after every regularity has been extracted, and what no further extraction can shrink. Hard randomness is an outcome that no prior specification fixes, however complete. Hard randomness is real, and the single outcome of a quantum measurement is the plainest instance of hard randomness. Pure randomness is an outcome with nothing at all accounted for. Pure randomness is an idealization, as determinism is. Determinism would perfect symmetry with continuity, pure randomness would perfect asymmetry with discontinuity, and the Incommensuration Theorem forbids both. The theorem says that two pairings cannot

hold exactly together at the foundation of one description: symmetry with continuity, and asymmetry with discontinuity. Every actual world lies between the two poles, determinism and pure randomness.

The concept of hard randomness is easier to see against a range of concepts. Determinism is the claim that nothing is unaccounted for: every outcome is fixed by what came before, always and completely. At the other end of the range, pure randomness is the condition in which nothing is accounted for: no outcome is fixed by anything before it. Pure randomness is an abstraction, as determinism is. Causality and choice lie between determinism and pure randomness, and causality and choice are the two concepts that actually describe the world we live in. Causality is the condition in which most things can be predicted most of the time: a consistent pattern of relations between events, perceived by an observer, holding to a degree. Choice is the condition in which some part of what happens can be predicted from what came before and some part cannot, and the part that cannot be predicted is the contribution of an agent, and not noise. Change is the superclass of causality and choice, the class that contains both, and change lies between the two on the range: causation is mostly predictable, choice is mostly unpredictable, and change, which holds both, is about half predictable. In the essay on determinism in Part I, I showed that the first end of the range, determinism perfected, lies beyond everything that can be put to a comparison. This essay is about what comes into the domain of comparison from the other end of the range: hard randomness, which is real.

II. Causation Is Not Determinism

The concept of hard randomness is hard to see clearly because of a habit of thought that is nearly universal among people who work in mathematical models, and I want to name the habit before going further.

The habit has three steps. First, one collapses change into causation: one takes whatever happens to be an effect of something prior. Second, one collapses choice into causation: one takes whatever an agent does to be one more effect, so that choice becomes a name for a causal process we happen not to have traced. Third, one identifies causation with determinism: one treats the pattern of causes and effects as a strict isomorph of the mathematical mapping that takes a complete state to a complete state. A strict isomorph is a match, feature for feature and without exception. At the end of the three steps only one concept is left, causation taken as determinism, and the concept of hard randomness has nothing left to name, because one has defined a residue that no cause accounts for out of existence before consulting any experiment.

Each of the three steps is a mistake, but the third step is the one that matters to this essay. Determinism is perfectly applied. Determinism is a mathematical, platonic notion (timeless, of the kind that holds of mathematical objects): a mapping that holds without exception, without time, without an observer. Causation cannot be perfectly applied. Causation is a pattern seen from inside time, from a standpoint, by a comparison, and causation holds to the degree that the pattern repeats. Determinism is atemporal, that is, outside time. Causation is temporal. Most physicists are entirely comfortable with atemporality inside a model. One can be comfortable with atemporality inside a model and still be making a mistake when the model's atemporality is carried across to the world. Carrying the atemporality across gives a position that can be logically consistent and philosophically inconsistent at once, which is to say, valid but not sound. The position is valid in that its conclusions follow from its premises. But the position is not sound, because its premises include an identity that does not hold: the identity of causation with determinism.

The physicist John Bell published Bell's theorem in 1964. On the reading I give in the preceding essay, Bell's theorem shows that the identity of causation with determinism fails. Bell's theorem shows that causation cannot be perfectly applied to the correlations of separated particles: there is more correlation in nature than any coherent notion of causality can ex-

plain. If causation cannot be perfectly applied, then causation is not determinism, whatever the models say. And if there is a strict difference between causation and determinism, then there is room for a residue that is causal in no sense. Hard randomness is the name for that residue.

III. Three Results Read Together

Three results of physics are each well understood when taken separately. Together, the three results establish that hard randomness is a real concept. If the concept is removed from a theory, the theory ceases to agree with experiment. The three results are Bell's theorem, Heisenberg's uncertainty principle, and Planck's constant. I take the three in turn, and then I say why the three matter together.

On the account I give in the preceding essay on Bell's theorem, the theorem shows that there are non-causal correlations in nature. Separated particles agree in ways that neither a shared past nor a passing influence can account for. No one can use the agreement to send a signal. The correlations are real, experimenters observe the correlations after the fact, and no causal process accounts for the correlations. The first result is therefore that there is something that causality does not cover.

The physicist Werner Heisenberg published his uncertainty principle in 1927. Heisenberg's principle shows that there is a limit of access, a limit on what any measurement can obtain. Picture the spin of a particle as if the spin were an axis pointing in some direction, at some angle to the measuring apparatus. If the angle had a definite value, the angle would be perfect information about the particle. But no experimenter obtains the angle from a measurement. A measurement is a single question, vertical or horizontal in the frame that the apparatus sets. The experimenter receives a single answer, and the act of asking reorients the spin that was asked about. No one can measure the angle in two perpendicular frames on the same particle. Nor can anyone evade the limit by preparing a correlated pair of particles and measuring one particle in each frame, because

the pair does not route around the limit: the perpendicular measurements come out uncorrelated. The angle is not merely unknown. The angle is unknowable, and the angle remains unknowable however good the technology becomes. The limit on knowing the angle is categorical: the limit is a limit into the unknowable, written into the mathematics of quantum mechanics. The limit is not a limit of engineering. The second result is therefore that there is a boundary past which measurement does not go.

At this point I add a reading of my own, about what the quantum state is. The quantum state is the description that quantum mechanics gives of a system. The quantum state is not a picture of a physical thing. The quantum state is the record of what has been found and of what a given setting of the detector makes possible. The record is the same for everyone who has the outcome. The quantum state is not anybody's private degree of belief. Nor is the quantum state knowledge of a hidden angle, since there is no hidden angle. The act of measuring is an interaction. The act makes one outcome actual, and the record of what can be known is updated to that outcome. The update of the record is not a physical change of the system (*The Quantum Passage*, Chapter 9, Section IV). The formalism of quantum mechanics describes what can be known by an interaction of a given kind, so where the formalism says that knowledge stops, the formalism is saying something about interaction, and not merely about ignorance. I mark this account of the quantum state as my interpretation. The argument of this essay does not require my interpretation, but my interpretation is the frame in which I find the argument most natural.

Planck's constant is the measure of the second result, the boundary past which measurement does not go. The number of Planck's constant expresses a unit, fixed by the definition of the kilogram since 2019. I quote the number from physics rather than obtain the number from anything in this book. Planck's constant measures a bound on joint knowledge: below the action it marks, no measurement distinguishes jointly what a pair of conjugate quantities would need to fix. Position and momentum are one pair of conjugate quantities. Planck's constant sets no least length and no least duration: how fine a comparison can be made depends on the energy

brought to it. Heisenberg's principle says that there is a boundary, and Planck's constant says how wide the uncertainty is at the boundary. The third result is therefore that the boundary has a scale.

Now I put the three results together. Bell's theorem says there are correlations that no causal process accounts for. Heisenberg's principle says there is a limit past which no measurement obtains information. Planck's constant says how much information is unobtainable. I stress that each of the three is an observation, experimentally supported and repeatedly confirmed, and the net effect of the three observations is that there is no coherent notion of causality that can explain all measurement results. So some measurement results are not explained in terms of causality. When a measurement result is not explained in terms of causality, the result is random, and since the failure of causality in that result is categorical rather than practical, the randomness is hard. Once hard randomness is asserted on the basis of actual experiment, the concept can no longer be discarded: the concept cannot be factored out of a theory that is meant to be consistent with what is measured.

IV. The Loophole-Closing Tests and the Razor

The history of the response of physicists to Bell's result shows the concept of hard randomness being forced on a community that did not want the concept.

When experimenters first observed violations of Bell's inequality, physicists responded that something must be wrong with the experiment. So experimenters did the experiment again, more tightly. Physicists raised objections. One objection was that the detectors might be too inefficient, so that the detected pairs were an unrepresentative sample. Another objection was that the settings of the detectors might be chosen too slowly. If the settings were chosen too slowly, a signal at light speed could have carried one setting to the other side. A third objection was that the settings might not be independent of the source of the particle pairs. Physicists

called each objection a loophole. Each loophole was a way in which a causal account of the correlations might after all have been available. Experimenters then designed experiments to close the loopholes. By the middle of the 2010s, in three tests published in 2015, the experimenters had closed the loopholes together. In the three tests of 2015 the experimenters separated the detectors by enough distance, chose the settings fast enough and randomly enough, and detected the particles efficiently enough that no causal account through any of the loopholes remained. The correlations still violated Bell's inequality.

After the loophole-closing tests the choice was stark: either one accepts superdeterminism, or one accepts hard randomness as a fundamental feature of reality. Superdeterminism is the position that everything is fixed at literally every scale, including the settings of the detectors, the random-number generators that chose the settings, and the experimenters who built the generators. On the superdeterminist position, a common past determined both the macroscopic arrangement of the laboratory and the microscopic state of the source.

I make a structural argument against superdeterminism in the essay on superdeterminism in Part III. But the structural argument is not needed to decide between superdeterminism and hard randomness. If superdeterminism is to survive the loophole-closing tests, superdeterminism needs excuses so extreme that Occam's razor applies on its own. Occam's razor is the rule that, of two hypotheses that account for the same observations, one should prefer the simpler. The superdeterminist hypothesis says: the whole of the past, at every scale, has been arranged so that the free choices of experimenters happen to conspire with the states of particles to produce exactly the correlations that a non-causal account predicts, while leaving no trace of the conspiracy anywhere else. The hypothesis of hard randomness says: some of what happens is not caused. The hypothesis of hard randomness is simpler by a very large margin. So we accept hard randomness and live with hard randomness.

V. Why Hidden Variables Cannot Help

One more attempt to avoid hard randomness deserves a direct reply, because physicists discuss Bell's result in the vocabulary of that attempt.

The hypothesis of hidden variables was the idea that something in the generator of the particle pairs might account for the correlations: something we do not know, but that has a definite state. If both particles carry the answer from the start, the agreement between the particles is no mystery. The hypothesis of hidden variables is the causal account by shared origin. In the preceding essay, on Bell's theorem, I said why Bell's inequality is the bound on the causal account by shared origin. I also said there why the measured correlations exceed the bound.

The point I make in this section comes logically before the arithmetic of Bell's inequality. Physicists proposed hidden variables as the basis of causation: the definite state from which the outcome follows. But when one tries to use the hypothesis as a model to predict the outcomes, one finds that causality has still been violated. The correlations still exceed what any definite state at the source can supply. And if causation has been violated, the variables make no difference, whatever the variables are. A variable is a placeholder for a cause, and a placeholder cannot restore causation after causation has been shown to be insufficient. So hidden variables do not make causation a way of accounting for the correlations. The program of hidden variables was a temporary argument: physicists tried the program, and the program failed. The failure of the program is what "no local hidden variables" means: no variable could have done the work the hypothesis needed done. The phrase does not mean that we looked for the variables and did not find them.

VI. Instances: Atomic Decay and the Three-Body Problem

So far I have argued that the concept of hard randomness is required, and now I point at hard randomness itself. Two examples, one direct and one indirect, show where hard randomness enters the world of ordinary scale.

The direct example is atomic decay. An unstable nucleus will decay, and the rate at which a population of unstable nuclei decays is among the best-measured regularities in physics. But nothing predicts the moment at which a single nucleus decays. There is no internal clock we have failed to read, and no hidden state that is winding down. The statistics of decay are lawful, and the individual decay is not. Atomic decay is hard randomness in its purest observed form. An atomic decay is a phenomenon that could not be predicted on the basis of any past knowledge, because no capacity for causal prediction exists for atomic decay. Atomic decay is the better of the two examples precisely because there is nothing, no clock and no hidden state, to appeal to. A quantum event at the scale of atoms produces an observable result at the scale of laboratory instruments by amplification. Physicists build a detector so that one microscopic event sets off a cascade: in a Geiger counter, a single ionization (an electron knocked off an atom) starts an avalanche of further ionizations, and the avalanche ends as a pulse of current that a counter registers.

The indirect example is the three-body problem, and through the three-body problem, the weather. Picture three bodies that come together and collide: three balls on a table that touch at once and rebound elastically, without loss of energy. Which way does each ball go? The outcome depends with extreme sensitivity on exactly how the three balls come together: on differences in position and timing that can be made as small as one likes while still changing the result entirely. The sensitivity of the three balls is not a special case. A great deal of what happens in nature

amplifies very small differences, and the weather is the familiar instance: the weather is sensitive to its initial conditions in a way that makes long-range prediction fail no matter how good the model.

Now follow the amplification downward, toward smaller and smaller differences. The differences that decide the outcome can be made smaller and smaller. At some point the differences fall below the limits of measurement, below the microscopic limit. The space of states is the range of all the states that a system could be in. Below the microscopic limit, the space of states has cells, and differences inside one cell are not distinct states. At that point no one can know the microstate of the system, its exact state in every detail, because there is no instrument for the microstate, and not because our instruments are poor. And yet the system still produces an outcome. What produces the outcome? The outcome is produced by whatever is happening at the scale below the boundary of measurement, and from the standpoint of anything inside the domain, whatever happens below that boundary is hard random. Atomic decay happens below the limit all the time and everywhere, and sensitive dynamics above the limit amplify the decays. Add the non-causal correlations of Bell's theorem, which appear in ways that could not have been expected in advance, and the picture is of a world in which the incompressible residue seeps upward through every process that amplifies what the process cannot resolve. The residue is therefore found outside the laboratory as well as inside it.

VII. The Microscopic Limit as a Categorical Boundary

I have been calling the microscopic limit a boundary. Now I say what kind of boundary the microscopic limit is, because the whole case for hard randomness as a fact about the world depends on the answer.

The domain of comparison is the domain within which physics is done, and the domain of comparison is specified by the notion of measure. A thing is in the domain when the thing is measurable: when the

thing is capable of entering into an interaction that yields a signal an observer can compare with another signal. Planck's constant marks the microscopic limit, and the microscopic limit is where no interaction yields a signal that an observer can compare: below the action that Planck's constant marks, no measurement fixes jointly what a pair of conjugate quantities would need. What lies below the microscopic limit is inaccessible with any measurement tool that could be built, and not only with the tools we have, because a tool is itself an interaction and the limit is a limit on interaction. The boundary is therefore categorical. The boundary marks where measurement itself gives out, and where the domain gives out with measurement. The boundary does not merely mark where our technique gives out.

There is a second boundary of the same kind at the other end of the domain, and the concept of hard randomness becomes clear when one sees the two boundaries together. At the macroscopic edge of the domain, the edge of the very large, there is a horizon past which no signal can reach us. Whatever is farther away than the light that has had time to arrive is unseeable in principle. The horizon is the edge of what one observer can ever compare with, and not an edge of the universe. Light from beyond the observable universe has not had time to reach us in the 13.8 billion years since the present expansion began, the age that measurements of the cosmic microwave background give (Planck Collaboration, 2020). Light from beyond the cosmological event horizon never will reach us. Zero measurable signal comes from too far away. In exactly the same sense, zero measurable signal comes from what is too small. I develop the macroscopic edge in the essay on the domain boundary in Part III, and both edges together in the essays on the three horizons and on the microscopic boundary in Part IV. In this essay I need only the parallel between the two edges, the microscopic edge and the macroscopic edge. In the sense of this essay, a boundary is an edge past which there is no coherent signal. From beyond either edge there is no meaningful measurement.

Now place the two ends of the range of Section I, determinism and pure randomness, at the two edges of the domain. Determinism describes what lies beyond the macroscopic boundary: the completed, the fully specified, the whole seen at once. The whole seen at once is the omniscient ideal, the ideal of the mode of structure. No signal from inside the domain can reach the whole seen at once. Determinism, if it could hold, would have to be made good all the way to the scale of the absolute microscopic, the scale of exactly zero. Pure randomness describes what lies beyond the microscopic boundary: that from which no signal reaches inside the domain. Beyond the microscopic boundary the randomness would be, in a strict sense, perfected, and so pure randomness is an abstraction, as determinism is. Hard randomness is what comes through the microscopic boundary. From our perspective, anything that comes through the microscopic boundary can appear only as random, because no signal could come up through the boundary carrying the information that would make the thing appear otherwise. The word "hard" in "hard randomness" names the categorical character of the microscopic boundary. Causal knowledge is made of signals, and the boundary is defined by the absence of signals. So what arrives through the boundary can never be reduced to causal knowledge.

The categorical character of the boundary has a consequence for what we can assume, and I state the consequence without softening. Can we assume that there is something beyond the boundaries of the domain? No. For some boundaries, "beyond" is not defined at all. The limit that the Incommensuration Theorem sets is a boundary for which "beyond" is not defined: in the words of my book *Incommensuration*, the limit is "the curvature of the field itself, rather than a wall at the edge of an otherwise open field" (*Incommensuration; The Theorem and the Three Axioms*, Chapter 6, Section XI). Where a beyond is defined, as the region past the horizon of one observer is defined, we still cannot assume anything about what is there, because there is no way to tell what is there. To tell, one would have to interact with what is there, and an interaction would produce a predictable outcome, a signal. From beyond the boundary there is no signal. So

there is no hypothesis to be made about what lies beyond the boundary, and a hypothesis offered anyway is more than hand-waving, because a hypothesis offered anyway is a pretense of knowing what is, by construction, unknowable. What lies outside the limits of the domain is unknowable. The unknowability of what lies outside the limits is the whole of what can be said about what lies outside, and to say more is a failure of epistemic consistency (consistency between what one claims to know and what can be known), a failure that I decline to commit in this book. I take up the unknowable as a theme in its own right in the essay in Part IV on what physics cannot reach.

> **Constant and Limit**
>
> Planck's constant and the microscopic limit are distinct in the way that a number and a reading of the number are distinct. The number of Planck's constant has been fixed by the definition of the kilogram since 2019, and the number of the speed of light has been fixed by the definition of the meter since 1983. So the two numbers express units. What physics measures are the dimensionless ratios (ratios that carry no unit) that the two definitions leave untouched (*Measurement*, Chapter 7). The limit is the reading of the constant as a boundary of the domain of measurement. I make claims about the limit, as a boundary, and no claim about the number. For the speed of light too, I make claims about the boundary and none about the number: the number of the speed of light expresses a unit, and the boundary at the macroscopic edge is a reading of that number.

VIII. Randomness, Choice, and the Real

Two tasks remain: to say where hard randomness belongs in the structure of the metaphysics of this book, the account of what is real at the most basic level, and to say what this essay leaves to another essay.

In the modal alignment that I hold fixed throughout this book, the microscopic domain falls under the transcendent: the modality of the potential, the creative, the generative, of possibility and choice. The macroscopic domain falls under the omniscient: the modality of the structural, the repeatable, the lawful, of existence and pattern. Reality itself is the domain of interaction in which we live, and reality is immanent and lies between the microscopic and the macroscopic. Hard randomness is what the transcendent edge of the domain looks like from inside the immanent: possibility entering the real without a prior structure that fixed the possibility. Determinism is what the omniscient edge would look like if a signal could come from that edge: structure complete, with no possibility left. *An Immanent Metaphysics* says that causality is omniscient, change immanent, and choice transcendent, and the two boundaries of the domain are the two places where the immanent runs out into the omniscient and the transcendent, which are conjugate to each other.

The modern habit of Section II is the habit of collapsing change and choice into causation, and causation into determinism. Once the alignment is seen, the habit appears as what the habit is: an attempt to account for all change by causation. To account for all change by causation is to account for all change by the omniscient alone. At one point in history, people attributed all change to local deities. People in the modern world have attempted the opposite reduction, and hold, mostly without saying so, that all change is causation. Physicists have been forced by quantum mechanics to re-evaluate the reduction of all change to causation. The metaphysics of this book contains the reconciliation of the two reductions: change is the superclass, the class that contains both causation and choice. Some aspects of change are accounted for by causal knowledge, other aspects are accounted for by choices made by agents, and choice is as much a way of accounting for change as causation is. We know that we cannot predict choices, because a choice that we could predict would be causal and not choice. There is an inherent unpredictability in choice, and the

unpredictability in choice is hard randomness seen from inside: from outside, randomness; from inside, choice; one event, two descriptions, both correct, neither complete (*Measurement*).

What is not determined is not determined at all, and so randomness that comes from what is not determined is, wherever it appears, hard in the strictest sense. The specific content of a hard random instance could not be predicted, and could not have been predicted, on any basis at all, theoretical or conceptual or practical. Suppose one knew absolutely the position and the momentum of every particle in the universe, and, like God, also knew absolutely and omnisciently every law of nature, every argument and every reason. All of that knowledge together would still not be enough to fix the value of any hard random measure. The omniscient cannot contain the transcendent. The transcendent is the creative matrix out of which the immanent comes, and the transcendent must have and be and become things that are inherently and fully unknowable, in completeness and in totality, whatever else holds. The limit on knowing the transcendent cannot be surpassed or trespassed on by any amount or perfection of the omniscient, of argument or of the process of reason. The limit is law: involute (turned back on itself), inherent and absolute, and those three features are themselves a triple.

One further point remains. Hard randomness is more than a gap into which physicists have been forced to admit noise, because, on my definition, hard randomness is distinguished from soft randomness by being a fact about the world and not about our knowledge. But from a purely third-person, structural standpoint, hard randomness and soft randomness are indistinguishable: both produce the same statistics, both are equally unpredictable, and the outcomes show no pattern by which an observer could tell the two apart. The distinction between hard and soft randomness is real, but the distinction is registered from a perspective, in a present. In *Accessing the Real* I argue that the distinction is registered from a perspective, in a present, and the argument is that hard randomness, subjectivity, and the direction of time are distinct, inseparable, and non-interchangeable. In *Incommensuration; The Theorem and the Three Axioms* I de-

rive both the binding of the three and hard randomness itself from the Incommensuration Theorem: hard randomness is the irreducible residual that the theorem shows must exist. I do not repeat the argument or the derivation in this essay. In this essay I give the physical face, the form in physics, of one member of the triple of hard randomness, subjectivity and the direction of time. If a reader wants to know why the residue is more than ignorance in disguise, the reader will find the answer in *Accessing the Real* and in *Incommensuration*. In the essay on the structural arrow of time in Part III, I give the physical face of a second member of the triple, the direction of time.

IX. Summary

The central claims of this essay are readings of known results. The first reading is that Bell's theorem, the uncertainty principle and Planck's constant, read together, are the physical face of an incompressible residue that the Incommensuration Theorem requires. The second reading is that atomic decay and microstate amplification are instances of that residue entering the domain. Two other claims of this essay are structural exclusions. The first structural exclusion is that the microscopic limit is a categorical boundary, and the second structural exclusion is that nothing can be assumed about what lies beyond the microscopic limit. The two structural exclusions say what physics will not find, and why no theory can say anything about what lies past the boundary.

Hard randomness is the incompressible residue: that part of what happens which no causal knowledge could have fixed in advance, because there was nothing prior to fix that part. Hard randomness is distinguished from soft randomness, the randomness of ignorance, by being a fact about the world. Hard randomness is also distinguished from determinism and from pure randomness. Determinism and pure randomness are the two

ends of one range, and both are extrema, limits that lie beyond the domain. Causation and choice are the two concepts that describe the world between the two ends. Hard randomness is the residual met in that world.

Physicists did not want the concept of hard randomness and were made to accept it. Bell's theorem shows correlations that causality cannot cover. Heisenberg's principle shows a limit of access that no tool crosses. Planck's constant measures how much is unobtainable. After the loophole-closing tests only one causal escape remained, superdeterminism, and superdeterminism asks so much of the world that Occam's razor rules superdeterminism out. In atomic decay, hard randomness is seen directly. In the three-body problem, and in every process that amplifies what the process cannot resolve, hard randomness is carried up into ordinary scale.

The boundary through which the residue enters is categorical. The boundary is the edge of the domain of measurement, and the domain is defined by measure. From beyond the boundary there is no signal. What arrives without a signal preceding it can only be random, as seen from inside the domain. Nothing can be said about what lies beyond the boundary. Within the boundary there is a world that is lawful, causal, and open at its microscopic edge to possibility. As I argue in the companion volume, *Accessing the Real*, the world is open at that edge also to a perspective and to a direction of time, which the world cannot have without its openness to possibility.

KEY CONCEPTS IN THIS ESSAY

- **Hard randomness**: the residue of what happens that no prior causal knowledge could have fixed, not for want of instruments or theory but because nothing prior contained the residue; a fact about the world, not about knowledge.
- **Soft randomness**: unpredictability that reflects a limit of knowledge and could in principle be reduced by better instruments, computation, or theory.

- **The range**: determinism (nothing unaccounted for), causality (most things, most of the time), choice (part predictable, part not), pure randomness (nothing predictable); the two ends lie beyond the domain and are abstractions, the two middle terms describe the world, and hard randomness is the residue that comes into the world through the microscopic boundary.
- **Causation and determinism**: causation is temporal, perceived, and holds to a degree; determinism is atemporal, mathematical, and holds without exception; the identification of causation with determinism gives a position that is valid but not sound.
- **The three results**: Bell's theorem (non-causal correlation), Heisenberg's uncertainty principle (a categorical limit of access), Planck's constant (the measure of that limit); together the three results make hard randomness a concept that cannot be factored out.
- **Loophole-closing tests**: the experiments that removed every causal channel by which a Bell violation might have been explained, leaving superdeterminism or hard randomness; Occam's razor chooses the second.
- **Hidden variables**: a placeholder for a cause at the source; cannot restore causation once the correlations have exceeded what any cause can supply.
- **Microstate amplification**: the character of many natural processes, the three-body problem among them, of magnifying differences that lie below the limit of measurement into macroscopic outcomes; the channel by which the residue enters ordinary scale.
- **Planck's constant and the microscopic limit**: the number of the constant expresses a unit, fixed by definition; the limit is the reading of the constant as a boundary of the domain of measurement, a bound on joint knowledge relative to energy, with no least length.
- **Categorical boundary**: a limit defined by the absence of any signal, not by the weakness of current tools; the microscopic and macroscopic edges of the domain of comparison are both of this kind.

- **The unknowable**: what lies beyond either boundary; no hypothesis about what lies beyond can be supported, because no interaction with it is possible.
- **Choice, change, causality**: the foundational triple; change is the superclass; some change is accounted for by causation and some by choice; the unpredictability in choice is a meaningful hard randomness.
- **The bound triple**: hard randomness, subjectivity, and the direction of time, distinct, inseparable, and non-interchangeable; set out in *Accessing the Real*, derived from the theorem in *Incommensuration*, and pointed to here.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.45-1 (distinct, inseparable, non-interchangeable); 1.85-4 (causality, change, and choice); the section Causality and Determinism (Technical Appendix).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The essay on the binding of subjectivity, temporal direction, and hard randomness.

Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

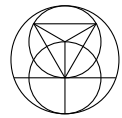
Hensen, B., et al. "Loophole-free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres." *Nature* 526 (2015): 682–686.

Giustina, Marissa, et al. "Significant-Loophole-Free Test of Bell's Theorem with Entangled Photons." *Physical Review Letters* 115 (2015): 250401.

Shalm, Lynden K., et al. “Strong Loophole-Free Test of Local Realism.” *Physical Review Letters* 115 (2015): 250402.

Planck Collaboration. “Planck 2018 Results. VI. Cosmological Parameters.” *Astronomy and Astrophysics* 641 (2020): A6.

Landry, Forrest. *The Quantum Passage; Quantum Mechanics from the Structure of Comparison.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-073-2. Chapter 9, Section IV (the update of the state is not a physical process).



Essay 7

The Deep Why

The Six Questions
and the Boundary of the Physical Domain

ABSTRACT

Within any domain of inquiry there are six classes of question: who, what, how, why, where, and when. In the metaphysics on which this book rests, the six questions are the epistemic face of six measures: mass, space, force, time, probability and possibility. The epistemic face of the six measures is the face that the six measures show to knowing. So each question is a request for one measure, and an answer of the right kind supplies that measure. In this essay I apply the correspondence between the six questions and the six measures to physics. Physics answers what, where, how and when. Physics also answers the why that asks for a cause or a law. I call the why that asks for a cause or a law the shallow why, and a more general what answers the shallow why. The deep why is the why that asks for the possibility from which a whole world is chosen. Physics does not answer the deep why, because the possibility from which a whole world is chosen exceeds any particular domain, and the method of physics is confined to one domain. The clearest example of the deep why is the question of why there is something rather than nothing. The question of something rather than nothing is about possibility, and possibility is the one measure that no measurement within a world can return. In

this essay I locate the question of something rather than nothing among the six questions. I distinguish the question from the what questions that metaphysics also asks, and I say what the location establishes.

Note on framework. This essay depends on two chapters of my book *Accessing the Real*. The two chapters are the chapter on the six types of questions and the chapter on the six measures. In this essay I also rely on the essay on the six measures and the six intrinsics, earlier in this volume. In this essay I use the modal alignment that I fix in the Introduction. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Six Questions

Every language that admits inquiry provides some way to ask about the agent, the object, the method, the reason, the place, and the time. The words differ from one language to another, but the distinctions underneath the words are constant. In every language that admits inquiry there is a way to ask who acted, what is there, how a thing was done, why the thing happened, where the thing is, and when the thing occurred.

The constancy of the six distinctions across languages has a reason outside grammar. I give that argument in the chapter on the six types of questions in *Accessing the Real*. I set out the bindings of the six questions in *Comparison; The Necessary Basis* (Chapter 6): the assignments that tie each question to its measure and each pair of questions to its modality. The six questions are the six measures turned into requests. In *An Immanent Metaphysics* I name the six measures: mass, space, force, time, probability, and possibility. The correspondence is one to one: each question is a request for exactly one measure, and each measure is requested by exactly one question. A what question is a request for mass, in the combined sense of inertia, pattern, form, and structure: what is there, what persists, what a

measurement finds. A where question is a request for space: the position, the configuration, the setting of the pattern. A how question is a request for force: the mechanism, the coupling by which one thing engages another, the dynamics by which an outcome comes about. A when question is a request for time: the moment, the sequence, the placement in the flow. A who question and a why question are in the same column of the grid of the six measures (Section II says more about the grid): the column of probability and possibility. A who question is a request for the agent, the one who made the choice. The choice is weighed among the alternatives that the agent could have taken. A why question is a request for possibility: the space of alternatives within which the outcome asked about counts as one alternative. A why question is also a request for the principle from which the outcome follows.

In this essay I take the correspondence as given, without restating the argument for the correspondence, and I ask what the correspondence says about physics.

II. What an Answer Supplies

The correspondence includes a grouping of the six questions into three pairs. The grouping follows the grid of the six measures. I set out the grid in the essay on the six measures and the six intrinsics, earlier in this volume. I draw the grid in the focus of the six measures (*Comparison*, Chapter 6, Section VII). The focus of the six measures is the framing in which the six measures are what is in view. In the focus of the six measures, mass in space has the nature of the omniscient, force in time the nature of the immanent, and probability in possibility the nature of the transcendent. The omniscient, the immanent and the transcendent are the three modalities that the Introduction describes: the omniscient is the mode of structure, the immanent the mode of process, and the transcendent the mode of the generative. Each pair of measures is a content in a

context. A content is what is being compared, and a context is the frame of the comparison. Mass, force and probability are the contents of the three pairs. Space, time and possibility are the contexts.

The what question and the where question are mass in space. The what question and the where question have the nature of the omniscient: the structural, the repeatable, the shareable, what exists and where it is. A what answer names a pattern, and a where answer locates the pattern. Together the two answers say what the world contains and how the contents of the world are arranged.

The how question and the when question are force in time. The how question and the when question have the nature of the immanent: the processual, the interactive, the here and now. A how answer gives the mechanism, the coupling by which the outcome came about, and a when answer places the outcome in sequence, so together the two answers say what is happening and by what dynamics.

The who question and the why question are probability in possibility. The who question and the why question have the nature of the transcendent: the evaluative, the potential, the generative. A who answer names the agent whose choice is at issue. In the full sense of why, a why answer gives a principle from which a realized structure follows. Both answers go beyond pattern: both are about the possibility within which a pattern is one alternative.

> **On a Second Grouping of the Six**
>
> The six questions admit a second grouping, and I give both groupings in the companion essay on the six types of questions, in *Accessing the Real*. In the second grouping, the questions are grouped by what each question *does* rather than by what each question is *about*. In the second grouping, the who question and the what question form an axis of the subjective and the objective, the where question and the when question form an axis of space and time, and the why question and the how question form an axis of abstraction and instruction. The grouping into three pairs is the content view of one structure, and the second grouping is the function

> view of the same structure. The two views agree on the point on which this essay depends: a what question is answered by a pattern, and a why question, in the full sense of why, goes beyond pattern to possibility. In the function view, how questions and why questions run in opposite directions across one span, the span between principle and instance: a how question descends from principle to instance, and a why question ascends from instance to principle. I use the content grouping in this essay because the content grouping is the binding in the focus of the six measures, and the measures are what physics measures.

The argument of this essay depends on one further alignment. In *An Immanent Metaphysics* I align laws, axioms and principles with the omniscient, the immanent and the transcendent respectively. In *An Immanent Metaphysics* I also align knowing with the omniscient. I align understanding with the transcendent, in the sense in which understanding is what informs action. A what answer is a law-shaped answer, because a what answer has the nature of the omniscient, as a law does: a what answer says what is the case, in a form that can be checked, repeated, and shared. A full why answer is a principle-shaped answer, because a why answer in its full sense has the nature of the transcendent, as a principle does. A full why answer says what makes the thing asked about the kind of thing that could be the case at all. Knowing what is there is an answer of one modal character, and understanding why a thing is there is an answer of another modal character, so the difference between the two answers is not a difference of degree.

III. What Physics Answers

Physics answers what questions. What is the structure of the atom? What is the spectrum of hydrogen? What is the state of the system at a given time? The three questions are requests for pattern, and physics re-

turns pattern (a structure, a value, a state vector) in answers that are omniscient in character, because anyone with the instruments can write down, transmit, and confirm the answers.

Physics answers how questions. How does an electron move between energy levels? How does a gas reach equilibrium? The two questions are requests for the path by which the outcome comes about. Physics returns a mechanism, a dynamics, an equation of motion.

Physics answers when questions and where questions. Physics sometimes answers a when question or a where question with great precision. When will the eclipse occur? Where is the particle? Where physics cannot answer a when question or a where question exactly, as in the microscopic domain, physics reports the inexactness in the form of a distribution. A distribution is a spread of probabilities over times or places. The distribution is itself a what answer about the limits of when and where.

Physics rarely answers who questions. When physics does answer a who question, the who is usually a which: which body exerted the force, which source emitted the radiation. In the full sense of the word, the agent is not among the things physics measures. The agent is missing from physics for a reason. Who and why are in the same column of the grid, the transcendent column, and who and why are the two questions that physics leaves aside: the two questions that are requests for possibility and for the choosing within possibility.

And physics answers a certain kind of why question. Why does the apple fall? The apple falls because massive bodies attract. Why is the sky blue? The sky is blue because shorter wavelengths scatter more strongly. Why does the pendulum keep time? The pendulum keeps time because the restoring force is proportional to the displacement, for small angles. Each of the three questions is a genuine why question, and each receives a genuine answer, and I do not want to say otherwise. But each of the three answers has the same form: each answer is a more general what. The apple falls because there is a law of attraction. The law of attraction is a pattern, a what, and the falling of the apple is an instance of the law. In

every case the why is answered by locating the instance under a law, and a law is a what at a higher level of generality: a pattern that holds, and so forbids whatever would depart from the pattern.

I call the why that is answered by a law the shallow why, and I use the name to mark the structure of the question. Nearly all of the explanatory work of science is done at the level of the shallow why. So I do not mean the name to diminish the question. The shallow why asks for the pattern of which the thing asked about is an instance. Physics answers the shallow why by supplying the pattern. The answer is omniscient in character: the answer is a law.

IV. The Deep Why

Anyone can ask the shallow why again, of the law that answered the shallow why. Why do massive bodies attract? Massive bodies attract because spacetime is curved by mass-energy. Why is spacetime curved by mass-energy? Spacetime is curved by mass-energy because the field equations say so. Why do the field equations hold? At the question of why the field equations hold, the answers stop, or rather the answers change kind.

The questions in the sequence form a regress, because each question in the sequence is asked of the answer to the question before. When the regress is carried to the laws themselves, there are three characteristic responses, and each response concedes the point I have just made: at the laws, the answers change kind. The first response is to say that the laws simply hold, and that there is no further why. The first response makes no false claim, but the first response is a refusal of the question, not an answer to the question. The second response is to say that the laws could not have been otherwise: some requirement of consistency selects the laws. The second response is a claim about the space of possible laws, which is to say a claim about possibility, and the method by which the second response is made is no longer measurement. The third response is to say that, among all the worlds that might have been, only some admit anyone

to ask the question. The third response too is a claim about the space of worlds that might have been. As with the second response, the method by which the third response is made is not measurement. Whoever gives one of the three responses has stepped out of the physical domain and is considering what the domain could have been. The way of stepping out differs from one response to another.

The deep why is the why that asks for the possibility from which a whole world is chosen. The clearest form of the deep why is the question that the philosopher Gottfried Wilhelm Leibniz put in his essay "Principles of Nature and Grace, Based on Reason": why is there something rather than nothing? I call the question of why there is something rather than nothing Leibniz's question. Leibniz's question is a why question in the full sense. Leibniz's question is about the existence of any pattern at all. So Leibniz's question is not a request for the pattern that our world is an instance of. Leibniz's question is a request for the possibility within which a world counts as one alternative and no world counts as another. On the account of the six measures, possibility is a context measure, the widest of the three context measures (space, time and possibility), and possibility is the space of outcomes against which any actual outcome is one. But Leibniz's question is about the possibility that exceeds every particular world, the possibility of there being a world, and not about the possibility space of any particular world.

Physics is the method proper to a single domain. Measurement is an interaction, and an interaction occurs between things that share a domain of comparison. Every what that physics returns is a what within the world that physics measures. Every how that physics returns is a path through the measured world. Every when and every where is a position in the measured world, and every shallow why is answered by a law of the measured world. The deep why asks about the relation between our world and the possibility of worlds, and the relation is not inside any world. The relation cannot be measured, because from within a world there is nothing to compare the relation against. In *An Immanent Metaphysics* I locate metaphysics as the study of the relationships between domains,

and physics as the study of the interactions within one domain, and in that book I mean by a relationship between domains a relation that cannot be measured from within any world. The deep why is a question of a different kind from the questions that physics answers, and not a question that physics has failed to answer and might yet answer with better instruments. The method of physics does not apply to the deep why, for the same reason that a ruler does not measure temperature. Nothing is missing from the ruler. In the picture of the ruler, the ruler is the method of physics and temperature is the deep why: the method of physics lacks nothing, and the deep why is a question of a kind that the method of physics does not answer.

Some people make one of two other claims in place of the claim that the deep why is a question of a different kind. The first claim is that the deep why is meaningless, because no observation could bear on the deep why. The first claim confuses the domain of physics with the domain of sense, the domain of what has meaning. The deep why is a well-formed question: the deep why asks for possibility, possibility is one of the six measures, and every act of measurement already presupposes each of the six measures, possibility among them. The second claim is that physics has in fact answered the deep why, by showing how a world can arise from a vacuum state, or from a law such as gravity acting on nothing. A vacuum state is the state of lowest energy, the state that physicists mean by empty space. The physicist Lawrence Krauss argues from the vacuum state in *A Universe from Nothing*, and the physicists Stephen Hawking and Leonard Mlodinow argue from the law of gravity in *The Grand Design*. There have been several accounts of how a world can arise from a vacuum state or from a law. Each account is an answer to a how question and to a what question: how a world of one kind develops from a state of another kind, and what the laws are under which the world develops. Each account of how a world arises presupposes the state and the laws from which the account begins. The accounts leave the presupposed state and laws unexamined. Yet the deep why asks about the presupposition, so the accounts leave the deep why unanswered.

I take up Leibniz's question on its own terms in *Third Resolutions in Western Philosophy*, and I do not repeat that book's treatment in this essay. In this essay I add only one thing: where Leibniz's question falls among the six questions. Leibniz's question is a why question and a request for possibility, and possibility of the kind that Leibniz's question requests is the measure that no measurement within a world can return.

V. The What Questions of Metaphysics

One mistaken conclusion is that metaphysics asks why and physics asks what, as if the two disciplines divided the six questions between them. But metaphysics asks what questions too, and most of the work of metaphysics is done with what questions.

What is the nature of existence? What is the nature of creation? What is the relation between self and reality? What is the structure of comparison? All four are what questions: they are requests for pattern, for the structure that persists, for what is there. But the four questions are what questions about the structure of possibility itself, not what questions about the contents of any particular domain. The Incommensuration Theorem is a what answer: the theorem says what the structure of comparison is, and which conjunctions the structure of comparison forbids, namely symmetry with continuity, and asymmetry with discontinuity, each pair applied absolutely and together. The Introduction states three axioms, and the three axioms are what answers about the relation among the three modalities, the immanent, the omniscient and the transcendent. The six intrinsics are a what answer about what any comparison involves: sameness and difference, content and context, the subjective and the objective.

So physics and metaphysics differ in the domain that a question is asked of, and not in the question word that each discipline uses. Physics asks what, where, how and when of a world from within that world by measurement. Metaphysics asks what, how and why of the relation between worlds and their possibility. The method of metaphysics is not

measurement, because measurement presupposes what metaphysics is asking about. The deep why is the question at which the difference between physics and metaphysics becomes unmistakable, because the deep why is the one question that cannot be rephrased as a what within the world.

The difference between physics and metaphysics has a consequence for how this book should be read. Nearly every claim in this book is a what claim. In the essays of this book I say what the structure of comparison is, what physics is an instance of, and what physics will not find, given the structure of comparison, but I do not say why there is comparison. In the essay on what physics cannot reach, in Part IV, I come back to the limit of what I say in this book from the other side, by asking what the metaphysics itself cannot say.

VI. Summary

One claim of this essay is a claim of the metaphysics itself: there are six questions, each asking for one of the six measures. A second claim of this essay is a reading of what physics does: physics answers what, where, how and when, and the shallow why, and physics does not answer the deep why. The structural reason for the reading is the correspondence between the six questions and the six measures. In this essay I locate the deep why and say what kind of answer the deep why would take. I do not say that metaphysics answers what physics cannot.

There are six questions and six measures. What asks for pattern, where for space, how for force, when for time, and who and why for probability and possibility. Physics is the method of measurement within a world: physics returns pattern, space, time, and path, and physics also returns the law under which an instance falls, which is the answer to the shallow why and is a what at a higher level. Physics does not return the possibility from which the world itself is one alternative, because that possibility is not inside the world, and measurement is. The clearest case of the deep

why is Leibniz's question, why there is something rather than nothing. Leibniz's question is a well-formed question about possibility, and the question points past physics to the study of the relation between domains, which is what metaphysics is. Metaphysics asks what questions too, at the level of the relation between domains, and this book is made of what questions at that level.

KEY CONCEPTS IN THIS ESSAY

- **Six question types**: who, what, how, why, where, when; the six measures turned into requests.
- **Correspondence**: in the focus of the six measures, what asks for mass (pattern), where for space, how for force, when for time, and who and why for probability and possibility, why for possibility in particular.
- **Three pairs**: what and where (mass in space, omniscient); how and when (force in time, immanent); who and why (probability in possibility, transcendent); the binding in the focus of the six measures (*Comparison*, Chapter 6).
- **Shallow why**: the why that asks for the law of which this is an instance; answered by a more general what.
- **Deep why**: the why that asks for the possibility from which a world is chosen; not answerable by measurement within that world.
- **Law and principle**: laws are omniscient, principles transcendent; a what answer is law-shaped, a full why answer is principle-shaped.
- **Physics and metaphysics**: physics studies interactions within a domain, and metaphysics studies the relationships between domains; both ask what questions, physics of a world, and metaphysics of the relation between worlds and their possibility.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.43-6 (measurement as interaction); 1.53-6 (laws, axioms, principles); 1.85-8 (the six measures); 1.92-3 to 1.92-8 (the six question types and their correspondences).

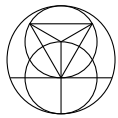
Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six types of questions; the chapter on the six measures.

Landry, Forrest. *Third Resolutions in Western Philosophy.* Wytheville, Virginia: UVSM Publications.

Leibniz, Gottfried Wilhelm. "Principles of Nature and Grace, Based on Reason" (1714). In *Philosophical Essays*, translated by Roger Ariew and Daniel Garber. Indianapolis: Hackett, 1989.

Hawking, Stephen, and Leonard Mlodinow. *The Grand Design.* New York: Bantam, 2010.

Krauss, Lawrence M. *A Universe from Nothing: Why There Is Something Rather than Nothing.* New York: Free Press, 2012.



Essay 8

The Wave and the Particle

The Two Survivors as the Two Faces,
and Why Every Duality Is a Triple

ABSTRACT

The four compounds of comparison are continuity, discontinuity, symmetry and asymmetry. The Incommensuration Theorem says that two pairings of the four compounds are forbidden as absolute conjunctions, symmetry with continuity and asymmetry with discontinuity, and that two pairings are valid absolute conjunctions: continuity with asymmetry, and symmetry with discontinuity. An absolute conjunction is a pairing of two compounds in which both compounds hold exactly, at the foundation of a description. I read the wave and the particle as the two valid conjunctions, appearing as the two faces of a physical description. The wave is continuity with asymmetry: the phase of a wave, which is how far along its smooth variation the wave is at a given point, varies without a break, and no two points along the wave are the same. The particle is symmetry with discontinuity: exchange two particles of one kind and nothing changes, and yet particles come in a definite number. If a description perfected both the wave and the particle at once, the description would be symmetry with continuity, which the Incommensuration Theorem forbids. So I offer the forbidden conjunction as the structural reason that no single picture captures both the wave and the particle. I then develop the claim that every duality is triadic, that is, made of three terms. A third term relates the two faces: the act of measurement, which is inter-

action. The act of measurement constitutes the two faces as a pair, so the act of measurement is not a complication added to the pair. In this essay I lean on a distinction that follows from the triadic claim: the distinction between dualism and duality. Dualism is the positing of two independent things, and dualism is unstable, because whoever holds a dualism must then account for how the two independent things interact, while duality is two faces of one comparison, and duality is real.

Note on framework. This essay depends on the Introduction, where I state the Incommensuration Theorem, on the essay on measurement as interaction, in Part I of this volume, and also on the chapter on duality and the Incommensuration Theorem in my book *Unlocking Reality*. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Two Survivors

The Introduction states the Incommensuration Theorem in full, and here I restate the theorem only as far as I need the theorem. The six intrinsics of comparison are the six features that belong to every act of comparison by its nature: sameness and difference, content and context, and the subjective and the objective. The content of a comparison is what is being compared, and the context of a comparison is the frame of the comparison. Applying sameness and difference to content and context yields four compounds, because the content of a comparison can be the same or different, and the context of a comparison can be the same or different. Continuity is sameness of content within sameness of context. Discontinuity is difference of content within sameness of context. Symmetry is sameness of content across difference of context. Asymmetry is difference of content across difference of context. When a compound holds exactly, at the foundation of a description, I say that the compound is applied absolutely. When any two of the four compounds are applied absolutely and

together, two conjunctions are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two conjunctions survive: continuity with asymmetry, and symmetry with discontinuity. I call the two conjunctions that survive the two survivors. I call continuity with asymmetry the first survivor, and symmetry with discontinuity the second survivor. The qualifier "applied absolutely and together" is part of the Incommensuration Theorem. Within any finite domain, symmetry and continuity co-occur, each to a finite degree. Symmetry and continuity cannot both be perfected at once.

My book *Unlocking Reality* has a chapter on duality, and in that chapter I observed that the two survivors are dual to one another: two structures are dual to one another when one exchange of terms carries each structure into the other. Exchange sameness and difference of context alone, putting "across difference of context" where a definition says "within sameness of context", and the reverse. Under the exchange of context alone, continuity (sameness of content within sameness of context) becomes symmetry (sameness of content across difference of context), and asymmetry (difference of content across difference of context) becomes discontinuity (difference of content within sameness of context). The exchange of context alone therefore carries the first survivor into the second survivor. Now exchange sameness and difference throughout, in the content and in the context alike. Under the full exchange, continuity and asymmetry are carried into each other, and symmetry and discontinuity are carried into each other. Each survivor is therefore carried into itself, and the two forbidden conjunctions are carried into each other. The two survivors are one structure seen twice, and the two forbidden conjunctions are also one structure seen twice. I argued from the two exchanges, in the chapter on duality, that complementary pairs should be expected wherever comparison occurs: pairs of descriptions of one thing in which both descriptions are needed and the two descriptions exclude each other. I named the wave and the particle in the chapter on duality as the clearest case in physics, but I did not work out how the wave and the particle correspond to the

two survivors. In this essay I work the correspondence out, and then I go one step further than the chapter on duality went, to the claim that every duality is triadic (Sections V and VI).

In the Introduction I also fix the modal alignment that this volume uses, in the focus of the two laws: the framing in which the law of symmetry and the law of continuity are what is in view. The modal alignment assigns terms to three modalities: the omniscient is the mode of structure, the transcendent is the mode of the generative, and the immanent is the mode of process. Three lines of the modal alignment are needed here. Symmetry has the nature of the omniscient. Continuity has the nature of the transcendent. Interaction has the nature of the immanent. I ask the reader to hold the three assignments in mind, because the three assignments return in Section V.

II. The Wave

Consider what a wave is, before we attach any physics to the word. A wave is a pattern that varies continuously through a medium or a field, and neighboring points of a wave differ by an amount that shrinks to nothing as the points approach each other. The smooth variation is continuity: sameness of content within sameness of context, the same quantity carried smoothly from one place to the next. But a wave is also something that goes somewhere: the phase of a wave, which is the measure of how far along the smooth variation one is at a given point, advances. At any one instant, no two points along the wave are in the same state. At any one point, the wave is in a different state at each instant. The advance of the phase is asymmetry: difference of content across difference of context. A wave is therefore the first survivor, continuity with asymmetry, and nothing else.

Try to remove the asymmetry and see what remains. Suppose the phase of a wave did not vary, so that every point of the wave was in the same state as every other point: then the wave would be a constant. The

constant would not propagate, would not interfere (add with another wave into a pattern of strong and weak places), and would not carry anything, and so the constant would not be a wave. Now try to remove the continuity, and suppose a pattern varied, but not smoothly: the pattern jumped from value to value with nothing in between. The jumping pattern would have no phase, because phase is the measure of how far along the smooth variation one is. Superposition is the adding of two waves, point by point, into one wave. The jumping pattern also could not superpose, because superposition depends on values defined at every point. So the jumping pattern would not be a wave either.

The wave, as a concept, is therefore the first survivor applied to a physical quantity. The differential equation is the native mathematics of the wave, the mathematics in which the wave is most directly written, and the differential equation is the mathematics of continuous change. Examples are the wave equation, the equations for the propagation of a field, and the Schrödinger equation, which the physicist Erwin Schrödinger found as the equation for the wave of a quantum system. Everything that is wavelike in physics is an expression of continuity with asymmetry: interference, diffraction, superposition and phase. Diffraction is the spreading of a wave around an edge or through an opening. On this reading, the physics of waves is the physics of the first survivor.

III. The Particle

Now consider what a particle is, again before we attach any physics to the word. A particle is a unit. A particle is here or is not here, and there is one particle or two or none. There is nothing between one particle and two particles. The jump from one to two is discontinuity: difference of content within sameness of context, a definite change in a fixed frame, with no intermediate. But a particle is also something that can be exchanged for another particle of its kind without any change. One electron is as good as another: swap two electrons, and no measurement can tell

that the swap was made. The swap that changes nothing is symmetry: sameness of content across difference of context. A particle is therefore the second survivor, symmetry with discontinuity, and nothing else.

Physics bears out the reading of the particle as symmetry with discontinuity through the exchange symmetry of particles, which is one of the deepest facts of quantum theory. Identical particles are indistinguishable in principle, and identical particles are not merely similar. Two kinds of statistics describe collections of identical particles: the Bose statistics and the Fermi statistics, named for the physicists Satyendra Nath Bose and Enrico Fermi. Under the Bose statistics, any number of identical particles can share one state. Under the Fermi statistics, no two identical particles can share one state. Both kinds follow from the requirement that the description of a collection be invariant (unchanged) under the exchange of any two of its particles. The countability of particles is likewise part of the structure of quantum theory. Particle number is an observable: a quantity that a measurement can return. Charge comes in units. The quantum numbers that label a particle are discrete, and a transition from one quantum number to another is a jump. The native mathematics of the particle is the mathematics of the countable: the eigenvalue (a definite value that a measurement can return), the conserved charge, and the quantum number that labels a particle.

Try to remove the symmetry. Suppose some measurement could tell one unit apart from every other unit. Then the unit would not be a particle of a kind: the unit would be an individual. Try to remove the discontinuity. Suppose a thing was exchange-invariant but came in no definite number, so that the thing could be half present. Then the thing would not be a particle at all, and would be more like a field intensity (the strength of a field at a point). Symmetry and discontinuity together are the particle, and neither symmetry alone nor discontinuity alone is a particle. In the Introduction I say that where physicists ask for perfect symmetry, they will find discontinuity, and that the discontinuity they find is quantization, the coming of a quantity in discrete units. The particle is what quantization looks like when quantization is given a name.

IV. Why No Single Picture Captures Both

The reading of the wave and the particle has so far been a matter of correspondence: the wave corresponds to the first survivor, and the particle corresponds to the second survivor. The main claim of this essay is what follows from the correspondence: why no single picture captures both the wave and the particle.

Physicists have known since the early decades of the twentieth century that light and matter each show both faces, the wave and the particle. Two effects show light arriving in units: the photoelectric effect, in which light knocks electrons out of a metal, and the Compton effect, in which light bounces off electrons as if in a collision between particles. Interference and diffraction show light propagating as a wave. Electrons diffract as a wave does, and electrons are also counted one at a time on a screen, as particles are. A classical picture is a picture drawn from the physics before quantum theory, and no single classical picture accommodates both faces. When physicists attempt to make one classical picture of both faces, they run into the familiar puzzles of the double slit. In the double-slit experiment, an experimenter sends particles one at a time through two narrow slits toward a screen, and the particles arrive at the screen one by one, as particles do. Yet over many arrivals the particles build up the striped pattern that a wave passing through both slits makes. The physicist Niels Bohr named the situation complementarity: the wave description and the particle description are each complete in its own domain of application, the two descriptions are mutually exclusive, and both descriptions are needed. Bohr did not say why complementarity holds.

On this account, the reason that complementarity holds is the Incommensuration Theorem. Suppose a description had both faces at once, with each face perfected: the description would then be fully continuous, with phase defined everywhere, and at the same time fully symmetric, exchange-invariant and countable, and so the description would be sym-

metry with continuity. The Incommensuration Theorem forbids two conjunctions, symmetry with continuity and asymmetry with discontinuity, when the two compounds of either conjunction are applied absolutely and together. The wave and the particle cannot be merged into one perfected picture for the same reason that the two survivors cannot be merged: the wave and the particle are the two survivors.

I want to be exact about what this reading claims and what this reading does not claim. The Incommensuration Theorem does not say that a physical system must be either a wave or a particle. Within a finite domain, symmetry and continuity co-occur, each to a finite degree. A wave packet is a wave bunched into a small region, and a wave packet has a rough location and a rough number. A particle has a de Broglie wavelength, the wavelength that the physicist Louis de Broglie assigned to every particle of matter. Both faces are present, in degrees, in every quantum system. Quantum mechanics contains the two faces at its two levels, the formalism and the findings. The wave is in the formalism of quantum mechanics, which is the mathematics in which the theory is written, and the particle is in the findings of quantum mechanics, what measurements return. The Incommensuration Theorem says that at the limit, where one face is made exact, the other face must recede and lose definition. If the number of particles is made exact, the phase is undefined, and if the phase is made exact, the number is undefined. The trade-off between number and phase is the number-phase relation of quantum optics, the physics of light treated as made of quanta. On this reading, the number-phase relation is the wave-particle case of the Incommensuration Theorem, written down as an inequality. The position-momentum relation is the trade-off between how sharply the position and the momentum of a particle are defined. I do not anticipate here the essay on the microscopic boundary, in Part IV, where I treat the position-momentum relation in the same way.

The account of complementarity in this section is a reading, in this book's sense. In a reading, I take a known result as an instance of the structure of comparison, and I claim that the structure of comparison is

the reason the result is true. Here I take complementarity as an instance of the structure of comparison, a structure not built for complementarity, and I claim that the structure is the reason complementarity holds. The reading does not re-establish complementarity, which physicists established on the evidence of physics alone. If the wave is the first survivor and the particle is the second survivor, then the impossibility of merging the wave and the particle is a consequence of comparison itself, and not a peculiarity of quantum mechanics. Then one should expect the same complementarity in any domain rich enough to have two modes of description, a continuous-asymmetric mode and a symmetric-discontinuous mode, and the expectation is qualitative and is the only prediction that I make in this essay.

V. Every Duality Is a Triple

The two survivors are dual, and so duality should be ubiquitous, as I argued in *Unlocking Reality*. What relates the two members of a dual pair? I take up the question because the wave and the particle are understood differently once the question is answered.

In every case of duality there is a third element that relates the two poles, the two members of the dual pair. For the wave and the particle, the third element is the act of measurement. The experimental arrangement determines which face the system shows, and the experimental arrangement is the interaction between the system and the apparatus. If the experimenter arranges to detect which slit each particle passes through, the particle appears. If the experimenter arranges to detect the pattern on the screen, the wave appears. The two faces are what the system shows under one interaction or under another. Without an interaction there is no showing, and so there are no faces. The two faces are not lying side by side in the system, waiting to be looked at.

A third element relates the two poles of a duality outside physics too. For subject and object, the third element is the relation between subject and object, which in my book *An Immanent Metaphysics* I name perception in one direction and expression in the other. Every subject is the subject of some perceiving, and every object is the object of some perception. The perceiving is neither the subject nor the object. For theory and practice, the third element is creation: the act in which a principle becomes a made thing. Creation is neither the principle nor the made thing. In each case, the dual pair cannot exist without the relation that constitutes the two poles as dual. Duality is always triadic: the two poles, and the comparison that shows the two poles.

In the Introduction I fix a modal alignment, which says what kind of triple the wave, the particle and the measurement are. The particle, as symmetry, is omniscient. The wave, as continuity, is transcendent. The measurement, as interaction, is immanent. The first axiom of *An Immanent Metaphysics* says of the three modalities: the immanent is more fundamental than the omniscient and/or the transcendent, and the omniscient and the transcendent are in conjugate relationship to one another. In the Introduction I identify the conjugacy of the omniscient and the transcendent with the Incommensuration Theorem itself. The wave and the particle are the conjugate pair, and the interaction is what the wave and the particle are a pair within. The third axiom says further that the immanent, the omniscient and the transcendent are distinct, inseparable, and non-interchangeable. Distinct: a wave is not a particle, and a measurement is neither a wave nor a particle. Inseparable: each of the wave, the particle and the measurement occurs only together with the other two. Non-interchangeable: the roles of the wave, the particle and the measurement cannot be swapped, and in particular the measurement cannot be made into a fourth thing of the same kind as the wave and the particle that the measurement relates.

Non-interchangeability matters, because the puzzles of quantum mechanics have usually been made by treating the measurement as a thing of the same kind as the wave and the particle that the measurement

relates. Suppose a physicist treats the act of measurement as one more physical thing, a wave or a particle among others. Then the measurement must be described by the same formalism that the measurement is supposed to decide. The description then regresses: something must measure the measurement. I develop the regress in the essay on measurement as interaction, in Part I. The triadic reading says why the regress arises: the regress comes from trying to interchange the immanent term of the triple, the measurement, with one of the conjugate poles of the triple, the wave or the particle.

VI. Dualism Is Unstable; Duality Is Real

I want to draw a distinction between two words that are often used as one: “dualism” and “duality”.

Dualism is the position that there are two independent things. Examples of dualism are mind and body, form and matter, and freedom and necessity. Wave and particle are a dualism too, when taken as two substances that a system somehow is at once. Whoever holds a dualism faces the same question at once: how do the two independent things interact? If the two things are independent, there can be no answer, because any interaction is a relation, and a relation between two things means that the two things were not independent. If there is an answer, the answer names a third term, the interaction. The third term is more fundamental than the two things, because the third term is what the two things are two within. So a dualism cannot stay a dualism. Whoever holds a dualism either denies the interaction or admits the interaction. If the interaction is denied, the dualism becomes two monisms that do not speak to each other. The two monisms are two separate views, each of only one kind of thing, with no relation between the two views. If the interaction is admitted, the dualism becomes a triad.

Duality is a different thing from dualism. Duality is the observation that one comparison has two faces, that the two faces are related by an exact exchange, and that the two faces cannot be merged into a single perfected picture. Whoever holds a duality posits one act of comparison and two structural consequences of the act, and posits no pair of substances. I put the point in these words in the chapter on duality in my book *Unlocking Reality*: one becomes two in relation, and the two, along with the one, are three. The most primitive triple of all is the triple of comparison, the first survivor and the second survivor: the act and its two faces.

In physics, the distinction between dualism and duality comes to two claims. Wave-particle duality is real: the two faces are exactly the two survivors, the exchange that relates the two faces is exact, and the Incommensuration Theorem says why the two faces cannot be merged. Wave-particle dualism is unstable. Suppose someone takes the wave and the particle as two things that a system independently is. The person must then explain how the wave and the particle are reconciled, and the need to explain shows that the person has already lost the third term and will have to bring the third term back under another name. I say that wave-particle dualism is unstable without prejudice against any particular interpretation of the formalism of quantum mechanics. One kind of interpretation is the pilot-wave account, such as the account that the physicist David Bohm proposed. In a pilot-wave account, physicists posit a wave and a particle, and then need a guiding relation by which the wave guides the particle. The guiding relation is the third term. In a wave-only account, physicists posit the wave alone, and then physicists need an explanation of why we see units. The explanation of why we see units is a theory of measurement, and measurement is the third term. Neither kind of account is refuted by the triadic reading, and I read each kind of account as confirming the triadic reading: whichever pole one starts from, one has to supply the interaction.

VII. Summary

Two of the claims I make in this essay are claims of the metaphysics itself: the Incommensuration Theorem with its two survivors, and the claim that every duality is a triple. I argue both claims from the structure of comparison alone. My account of the wave and the particle is a reading of a known result: in the reading, the wave is the first survivor, the particle is the second survivor, and complementarity is the forbidden merger of the two survivors. On the reading, the structure of comparison is the reason the known result is true. The expectation of the reading is qualitative: a complementarity of the same shape should appear wherever the two modes of description, the continuous-asymmetric mode and the symmetric-discontinuous mode, are both available.

The wave is continuity with asymmetry: smooth, and going somewhere. The particle is symmetry with discontinuity: interchangeable, and countable. Continuity with asymmetry and symmetry with discontinuity are the two survivors of the Incommensuration Theorem, and if a description perfected both the wave and the particle at once, the description would be symmetry with continuity, the conjunction that the theorem forbids. So no single picture captures both faces, and at the limit where one face is exact, the other face must recede. But the two faces are what one comparison shows under one interaction or another, and the two faces are not two things. The interaction is the third term, and without the interaction there would be no pair. Duality is always triadic. In a dualism the third term is forgotten, and so a dualism cannot hold together. In a duality the third term is kept, and a duality is real. One becomes two in relation, and the two, along with the one, are three.

KEY CONCEPTS IN THIS ESSAY

- **Wave**: continuity with asymmetry; the phase of a wave varies without a break, and no two points along a wave are the same.

- **Particle**: symmetry with discontinuity; exchange-invariant, discrete, countable.
- **Complementarity**: the two faces cannot be merged into one perfected picture, because the merger of the two faces is symmetry with continuity, a forbidden conjunction.
- **The third term**: the relation that constitutes a dual pair as a pair; for the wave and the particle, the act of measurement, which is interaction.
- **Duality is triadic**: two poles and the comparison that shows the two poles; the poles are conjugate (omniscient and transcendent), and the relation is immanent and more fundamental than the poles.
- **Dualism**: the positing of two independent things; unstable, because whoever holds a dualism must then account for the interaction of the two things, which is the third term that the dualism left out.
- **Duality**: one comparison with two faces related by an exact exchange; real, and always embedded in a triple.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.43-6 (measurement as interaction).

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapter on duality and the Incommensuration Theorem.

Bohr, Niels. "The Quantum Postulate and the Recent Development of Atomic Theory." *Nature* 121 (1928): 580–590.

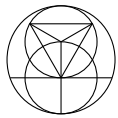
Einstein, Albert. "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt." *Annalen der Physik* 17 (1905): 132–148.

Bohm, David. "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables, I and II." *Physical Review* 85 (1952): 166–193.

Feynman, Richard P., Robert B. Leighton, and Matthew Sands. *The Feynman Lectures on Physics*, vol. 3. Reading, Massachusetts: Addison-Wesley, 1965. Chapter 1, Quantum Behavior.

PART III

Structural Exclusions



Essay 9

The Structural Impossibility of Superdeterminism

Why Determinism Extended to the Observer Fails a Fortiori, and Why Choice Cannot Be Collapsed into Causality

ABSTRACT

Superdeterminism is the proposal that the settings an experimenter chooses and the states of the particles the experimenter measures share a common causal ancestry. The common ancestry is a shared past that fixed both. The physicist John Bell proved a theorem that forbids certain correlations between distant measurements to any account that is both local and lawful. An account is local when no influence in the account crosses a distance in zero time, and lawful when the same physical law holds in the account at every place and time. On the superdeterministic proposal, a local and lawful account can produce the forbidden correlations after all. The reason is that the past determines the experimenter's choice of question along with the particle's answer. Superdeterminism has been argued with care by the physicists Sabine Hossenfelder and Tim Palmer. In public discussion, superdeterminism is often joined to a diagnosis: the standard account of why quantum mechanics is fundamental runs in a circle. I accept the diagnosis. In this essay I argue that superdeterminism is excluded before any experiment is run. Superdeterminism requires everything that determinism requires, and then requires more. In the essay on determinism, earlier in this volume, I identified what determinism requires as the conjunction of symmetry and continuity perfected. In de-

terminism, symmetry is the same law holding in every context, and continuity is the state specified without a gap at every point. Perfected symmetry and perfected continuity are total, with no exception. The Incommensuration Theorem says that symmetry and continuity cannot both be perfected at once. So the theorem forbids exactly the conjunction that determinism requires. What superdeterminism requires beyond determinism is the collapse of choice into causality. The collapse is the claim that the experimenter's choice is nothing but a consequence of prior conditions. The collapse is a category error, the mistake of treating something of one kind as something of another kind, because choice, change, and causality form a triple whose members are distinct, inseparable, and non-interchangeable. I agree with the proposal on two points, that time has a direction and that quantum mechanics is not the final word, but I show why each agreement tells against Hossenfelder's conclusion rather than for that conclusion. My argument does not depend on quantum mechanics, and no deviation from quantum mechanics would change my argument.

Note on framework. This essay depends on the Introduction for the six intrinsics, the four secondary compounds, the statement of the Incommensuration Theorem, and the three axioms. This essay also depends on the essay on determinism and causality, in Part I, and I extend the conclusion of that essay a fortiori: what holds of determinism holds all the more surely of superdeterminism. I draw on the essay on Bell's theorem, in Part II. The essay after this one in Part III is on causation, connectivity, and the domain boundary. In that essay I take up the faster-than-light half of the proposal examined here. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Proposal Under Examination

In recent years Sabine Hossenfelder and Tim Palmer have stated the position I examine in this essay more clearly than anyone else. I take the statement of superdeterminism by Hossenfelder and Palmer as the statement to answer, because the statement says plainly what superdeterminism needs. In public discussion, superdeterminism is often set within a proposal of three stages, and I take the proposal in that three-stage form, because each stage bears on the other two stages.

The first stage is the claim that the causal paradoxes usually attributed to faster-than-light influence can be avoided if time has a preferred direction that rules out causal loops, chains of causes and effects that return to their own beginning. The second stage is the claim that quantum mechanics is not fundamental: quantum mechanics is a statistical average over a deeper theory. On the second stage, the deeper theory is deterministic, and the variables that the deeper theory determines include the settings of the measurement devices. The second stage is superdeterminism, and Hossenfelder and Palmer develop the second stage in the works listed at the end of this essay. The third stage concerns the places where the deeper theory departs from the predictions of quantum mechanics. On the third stage, the departures might permit information to be sent faster than light. On the third stage, faster-than-light signals might even explain why we hear nothing from other civilizations: we are listening on the wrong channel.

The first stage is correct in what it says about direction. In Section V I say why this book's metaphysics agrees with the first stage. A preferred slicing is one privileged way of cutting space and time into successive moments. A preferred slicing would require more than a direction, and I do not grant a preferred slicing. But a preferred direction of time does not require superdeterminism. I argue in Section V that a preferred direction of time cannot be had together with superdeterminism. The second stage is

structurally excluded, and I devote this essay to saying why. I take up the third stage in the next essay. The next essay is on causation, connectivity, and the domain boundary of comparison. The domain of comparison is the range within which comparison, and therefore interaction, can occur. In the essay on causation I argue that the speed of light is, in its nature, the macroscopic boundary of the domain of comparison itself. So the speed of light is not the speed of any one thing. Therefore the question of signaling faster than light is malformed (wrongly posed), rather than merely hard to answer. Here I note only that the exclusion of the third stage does not depend on the exclusion of the second stage: superdeterminism is not available, but even if superdeterminism were available, superdeterminism would give no way to send a signal faster than light.

The impossibility I claim for superdeterminism does not depend on quantum mechanics. The impossibility depends on the structure of comparison, and the impossibility would hold in any physics that admitted measurement at all. I call the claim structural because the impossibility depends only on the structure of comparison. The defenders of superdeterminism recommend an experimental program of looking for deviations from the predictions of quantum mechanics, but because my claim does not depend on quantum mechanics, the results of that program cannot bear on my claim either way.

II. Superdeterminism as Determinism Strengthened

I set the two positions, determinism and superdeterminism, side by side.

Ordinary determinism is the claim that prior conditions together with law fix the state of every physical system. A lawful mapping is a rule by which the state of a system at one time fixes its state at another time. Determinism says that a complete specification of the state at one time, carried by the same lawful mapping in every context, yields a unique state at every other time. In the essay on determinism and causality, earlier in this

volume, I read determinism as a demand for two things at once. The first demand is that the same lawful mapping hold in every context. The same mapping in every context is sameness of content across difference of context, which is symmetry, and determinism requires symmetry perfected. Move the apparatus across the room, or run the experiment on Tuesday instead of Monday, and the same law holds: the law is the same content across a difference of context. The second demand is that the state be specified without a gap at every point, which is sameness of content within sameness of context, or continuity, and determinism requires continuity perfected as well. I state the Incommensuration Theorem in full in the Introduction. When a compound holds exactly, at the foundation of a description, the compound is applied absolutely. The theorem says that two pairs of the four secondary compounds of comparison are forbidden. The two compounds of either forbidden pair cannot both be applied absolutely at once. Symmetry with continuity is one of the two forbidden pairs. Within any finite domain, symmetry and continuity co-occur to a finite degree, but symmetry and continuity cannot both be perfected together. Determinism requires exactly that symmetry and continuity both be perfected together. So determinism is unreachable as a matter of structure, rather than false as a matter of fact.

Superdeterminism contains every requirement of determinism, and one further clause. Determinism fixes the states of the systems under study, while superdeterminism fixes also the choices of the experimenters about what to study: which detector setting to use, and which question to ask. Superdeterminists declare that the apparent freedom to choose the measurement is an illusion, and that the choice of setting and the state of the particle share a common causal ancestry, which extends back, if need be, to the initial conditions of the universe. The further clause has a specific purpose. Bell's theorem assumes that the settings of the detectors are statistically independent of whatever hidden state the particles carry. Statistical independence means that the settings are uncorrelated with the hidden state. Under that assumption, Bell's theorem and the loophole-closing experiments are inconsistent with every lawful and local account

of the correlations between distant measurements. I describe the loophole-closing experiments in the essay on hard randomness, in Part II. The experiments removed every causal channel by which the correlations might have been explained. Superdeterminists deny that the settings are statistically independent of the hidden state. If the settings were fixed along with the states of the particles, the correlations could be arranged in advance, and one account could have both lawfulness and locality.

The a fortiori argument is now short, and I give the a fortiori argument in full before I add anything to it. If determinism is unreachable, then superdeterminism is unreachable, because superdeterminism requires everything that determinism requires and then requires more. A position that requires a forbidden conjunction does not become available by requiring the same conjunction over a larger domain. Whatever cannot be had for the particles cannot be had for the particles and the apparatus and the experimenter together. Superdeterminism is therefore excluded before any experiment is run. Superdeterminism is excluded for the same reason that determinism is excluded. The reason is a reason about comparison, and not a reason about quantum mechanics.

The a fortiori argument is the whole of the argument that this essay inherits from the essay on determinism. The inherited argument is decisive on its own terms. If the reader accepts the essay on determinism, there is nothing further to establish, but the inherited argument does not examine the specific character of superdeterminism, and there is something specific to say about that character. The clause that superdeterminism adds is a claim of a different kind from determinism, and not merely a larger claim of the same kind, and so the added clause fails in a different way, which I set out in Section III.

III. The Category Error: Choice Collapsed into Causality

In this book's metaphysics I treat the real through a triple of concepts: choice, change, and causality. Choice, change, and causality are distinct, inseparable, and non-interchangeable in the same way as the three modalities are, and for the same reason. I give the reason in the next paragraph. In plain words: no one of the three can be reduced to another, each occurs only together with the other two, and to put one in place of another is a mistake. Causality is the lawful, repeatable, structural pattern that relates events to one another. Causality is what an observer sees when the same kind of cause is followed by the same kind of effect across many contexts, as when a dropped stone falls in every room and on every day. Causality has the nature of the omniscient, the mode of structure: of the repeatable, and of what holds regardless of who looks. Choice is genuine novelty: the emergence of what was not implicit in what came before, the singular act that is only itself. Choice has the nature of the transcendent, the mode of the generative: of the creative and the potential. Change is the actual process of transition: the interaction where pattern and novelty come together, and where either pattern or novelty can be noticed at all. Change has the nature of the immanent, the mode of process. Change is the superclass of choice and causality: the wider class that contains both.

I take the alignment of the triple with the three modalities from the metaphysics as fixed: causality is omniscient, change is immanent, and choice is transcendent. The third axiom says that the classes and instances of the immanent, the omniscient, and the transcendent are distinct, inseparable, and non-interchangeable. The triple of choice, change, and causality has the same status directly, because each member of the triple is an instance of one modality in the domain of the real.

In its added clause, superdeterminism is the attempt to collapse choice into causality. The added clause says that what appears as the experimenter's choice of setting is in fact nothing but a mechanistic consequence

of prior conditions. On the added clause, novelty is only the unfolding of what was already implicit, and the transcendent is only the omniscient seen from too close: what looks like novelty is pattern seen too narrowly to be recognized as pattern. In this book's metaphysics, the collapse of choice into causality is a category error. A category error is the mistake of treating something of one kind as something of another kind. I want to say exactly what kind of error the collapse is. The collapse is the error of attempting to reduce one modality to another across a boundary that, as the axioms state, cannot be crossed, and not the error of asserting something false within a domain where truth and falsity apply. Choice cannot be reduced to causality any more than causality can operate independently of change, or change can occur with nothing new in it. Choice, change, and causality remain three. When a proposal says that one of the three is really another, the proposal has not succeeded in saying anything about the real, and so the proposal could never turn out to be true.

I can also show from the Incommensuration Theorem itself, without depending on the axioms as stated, why choice cannot be collapsed into causality. What occurs has a lawful dimension, and the lawful dimension is both symmetry and causality. What occurs also has a completely specified dimension, and the completely specified dimension is both continuity and deterministic closure: the state fixed without a gap by prior conditions. Because symmetry and continuity cannot both be perfected, the lawful dimension and the completely specified dimension cannot both hold to the full. There is therefore always a residual: a domain in which the structural pattern does not fix the outcome. I name the residual choice. The name "choice" refers to what the theorem requires to be there in any world that admits comparison at all, and not to our ignorance of a pattern that is there. Superdeterminism is the claim that the residual is empty. The Incommensuration Theorem says that the residual cannot be empty.

For that reason I say that superdeterminism fails in two ways: as determinism fails, by asking too much, and also in its own way, by asking the wrong thing. In ordinary determinism, choice is already collapsed into causality for the systems that determinism describes, because determ-

inism requires that pattern be total, and a total pattern leaves no residual for choice. In superdeterminism the collapse extends to the comparer, the one who makes the comparison, because superdeterminism requires that the stance from which a measurement is made, the choice of what to compare, be pattern too. Ordinary determinism says that there is no novelty in what is measured. Superdeterminism says that there is no novelty in the act of measuring either, and so none in the comparison that makes a measurement a measurement.

On the Word "Free" in Free Choice

Superdeterminism is often presented as a denial of the experimenter's free will. Defenders of superdeterminism argue that physics has no business assuming free will in the first place. The argument of this essay does not assume free will either: my argument does not require that a human being who chooses a detector setting chooses by an uncaused act of the will. In the strongest Bell experiments, the experimenters took the settings from quantum random number generators, from the colors of light arriving from distant stars and quasars, and from the button presses of many thousands of people. The experimenters chose random number generators, starlight and button presses precisely so that no plausible common cause could influence both the setting and the particle. My claim is about the residual, and not about the experimenter. The claim is that in any world admitting comparison, the structural pattern leaves something unfixed, and that whatever selects the setting draws on that unfixed part in the same way that the particle does. Superdeterminism has to say that nothing draws on an unfixed part: that the structural pattern fixes everything, the setting included. The Incommensuration Theorem says that the structural pattern cannot fix everything, whether the setting was chosen by a person, a photon, or a star.

IV. Why the Residual Is Not Ignorance

A defender of superdeterminism has a natural reply, and I answer the reply directly. The reply is that the residual I have described is only what we do not yet know. On the reply, we do not know the initial conditions of the universe in detail, and the hidden variables are hidden. On the reply, a sufficiently complete description would fill the gap. Hidden variables are quantities, absent from quantum mechanics, that would fix each outcome. On the reply, the residual is epistemic (a gap in what we know), and I have merely dignified ignorance with a name.

The defender who makes the reply is mistaken about the kind of gap in question: an epistemic gap is a gap between a description that exists and our possession of the description. The Incommensuration Theorem says that a complete description, of the kind the reply imagines, is not the description of a comparison. And a world is what comparisons are of. The theorem does not say that the complete description is hard to obtain. If every state were specified without a gap, and every mapping held without exception, then nothing would remain to be measured. The reason is that measurement is the interaction in which content is compared across contexts, and in a world with no gap and no exception, both sameness within context and sameness across context would already be total. I develop the point that a world without gaps would leave nothing to measure in the essay on measurement, in Part I, where I use that essay's own terms. Here my point is only that a description in which the residual is closed is a description in which nothing happens, and a description in which nothing happens cannot be the description that the superdeterminist offers as an account of what happens in a laboratory.

For the same reason, local hidden variables cannot help the defender, whatever the local hidden variables are taken to be. In the essay on Bell's theorem I observed that a variable cannot restore causation after causation has been violated. The local hidden-variables program was an attempt to

account for the correlations causally, and the correlations exceeded what any causal account allows. Superdeterminism is a response to the failure of the local hidden-variables program, but superdeterminism is the wrong kind of response, because superdeterminism removes the independence that made the experiment an experiment, rather than adding a variable. A variable that is correlated with everything is the whole of the past, renamed, and not a hidden cause.

I add one more point, about method. I think the point about method is the strongest reason against superdeterminism for anyone who takes science seriously. The defenders of superdeterminism have rightly complained that critics dismiss superdeterminism by an appeal to its implications for free will, rather than answering superdeterminism on its physics. I have tried to answer superdeterminism on its structure, which is prior to its physics. But the structure of superdeterminism has a consequence that I noted from the side of method in the essay on hard randomness. On superdeterminism, every setting must be correlated with every state, including settings taken from starlight emitted before the earth existed, and so superdeterminism is invulnerable to any experiment. The ordinary principle of economy is Occam's razor: of two hypotheses that account for the same observations, one should prefer the simpler. By Occam's razor, superdeterminism is set aside before the Incommensuration Theorem is even applied. The Incommensuration Theorem says why Occam's razor was right to set superdeterminism aside.

V. The Arrow of Time Without Determinism

I said in Section I that the first stage of the proposal is correct, and here I say in what way the first stage is correct, because agreeing with the first stage turns out to exclude the second stage.

The first stage is the observation that time has a preferred direction. The proponents of the first stage invoke the direction of time to rule out causal loops. I agree with the first stage. Time has a direction. The direc-

tion of time is prior to the spatial metric, the measure of distance in space, rather than obtained from the spatial metric. The first axiom says that the immanent is more fundamental than the omniscient and/or the transcendent. Change is time as process and has the nature of the immanent, while pattern is space as structure and has the nature of the omniscient. So, by the first axiom, the direction of time is prior to the spatial geometry. In the essay on the structural arrow of time, later in this volume, I develop in full the claim that the direction of time is prior to the spatial geometry. In that essay I also argue that there is an arrow of time prior to the thermodynamic arrow, the direction in which disorder increases.

But I hold the direction of time to be one member of a bound triple, together with hard randomness and subjectivity, and so not an isolated fact that can be added to any picture. Hard randomness is the part of what happens that no causal knowledge could have predicted, because nothing prior fixed that part. I hold the three members of the triple to be distinct, inseparable, and non-interchangeable. I set out the binding of the triple in my book *Accessing the Real*. I derive the binding from the Incommensuration Theorem in my book *Incommensuration*, and I do not restate the derivation here. The binding has a direct consequence for the question of superdeterminism: no one can have both the directed time that the proposal needs in its first stage and the determinism that the proposal requires in its second stage. The direction of a process is constitutively linked to the emergence of genuine novelty: a process that goes somewhere is one in which what comes next was not already wholly there. Where prior conditions fix everything in a universe, the universe has no genuine temporal direction: the universe is a static block, with all of its times laid out together and none of them happening. In the static block, the label "earlier" is a convention adopted by a reader of the block, and not a feature of a process.

So there is a tension between the first stage and the second stage of the proposal, and the tension is exactly the Incommensuration Theorem: the two stages are not two independent commitments that merely happen to be held together. Directed time is asymmetry: difference of content across

difference of context, the later not the same as the earlier. Asymmetry is the compound that survives paired with continuity: the theorem allows the conjunction of continuity and asymmetry. Superdeterminism requires symmetry and continuity perfected together, and so no asymmetry is left over to be the arrow of time. The proposal needs the arrow of time to keep causality free of loops. The proposal also needs the static block to keep locality consistent with Bell's theorem. The proposal cannot have both the arrow and the block, for the same reason that no one can.

VI. The Circularity, and a Different Dissolution

The diagnosis of the standard position is the strongest part of the case for the proposal, and I give the diagnosis its due before I say where I think the superdeterminists' way out of the circle goes wrong.

The diagnosis says that the standard position runs in a circle, a chain of claims that returns to its own start. The speed of light must be a limit on signaling. Therefore no deeper theory can permit signaling faster than light. Therefore quantum mechanics, whose no-signaling result respects the limit, is fundamental. Therefore the speed of light is a limit. Defenders of the standard position take each step as support for the next, and the last step is the same claim as the first, so nothing outside the circle supports any step. The diagnosis is right that the standard position is circular. Superdeterminists escape the circle by breaking the circle at quantum fundamentality, the step that says quantum mechanics is fundamental. I call the superdeterminists' way out of the circle the superdeterministic escape. Superdeterminists deny that quantum mechanics is the deepest description, posit a deterministic theory beneath quantum mechanics, and accept whatever follows about signaling.

I break the circle at a different place, and I think at the right place: the speed of light is a limit because of the structure of comparison, and not because quantum mechanics is fundamental. The speed of light is the macroscopic boundary of the domain within which comparison, and

therefore interaction, can occur, and I make the argument for the boundary in the essay that follows this one. Here I say only that once the limit rests on the structure of comparison, the limit no longer needs quantum mechanics to support it, and so the circle no longer closes.

I also agree with the proposal on the other point, that quantum mechanics is not fundamental, though not in the proposal's sense. Quantum mechanics is a partial description. Quantum mechanics is symmetry with discontinuity, the tool proper to the omniscient, applied to the microscopic, which is the transcendent domain: the domain of possibility and probability, of what may occur rather than what has occurred. General relativity is the other partial description. General relativity is continuity with asymmetry, the tool proper to the transcendent, applied to the macroscopic, which is the omniscient domain: the domain of pattern, of space, of what holds across contexts. Quantum mechanics and general relativity are the two surviving conjunctions of the theorem, and the two theories are conjugate descriptions within a single domain of comparison. Each of the two theories captures what the other must leave out, and neither theory can be subsumed into the other. In each theory, the tool proper to one modality is applied to the domain of the other modality. In the essay on cross-modal reach, later in this volume, I show why the crossing is required and not accidental.

So quantum mechanics is not the final word, because quantum mechanics is one of two partial descriptions, general relativity being the other, and not because there is a deterministic theory beneath quantum mechanics. There is no theory beneath quantum mechanics whose findings perfect both survivors at once: the Incommensuration Theorem precludes any such theory. Superdeterminists escape the circle by replacing one error with another. The error of the standard position is to ground a structural boundary in a particular formalism, quantum mechanics. The error of the superdeterministic escape is to propose, as the deeper ground, exactly the conjunction that no theory can contain in its findings: symmetry and con-

tinuity perfected together. I ground the boundary in comparison instead, and I leave quantum mechanics and general relativity where they are, each doing what the other cannot.

VII. Independence from Quantum Mechanics

I still need to say why the experimental program that the defenders of superdeterminism recommend has no bearing on my argument.

Hossenfelder proposes testing superdeterminism by looking for deviations from the predictions of quantum mechanics in regimes where a deeper theory might become visible: small systems, repeated measurements, and short times. I have no objection to the experiments. Physicists should always look where physicists have not yet looked. But whichever way the result of the experiments comes out, the result does not bear on the question of this essay. Suppose that the experiments find no deviation. Then quantum mechanics remains as it was, and my reading of quantum mechanics remains as well. Suppose instead that the experiments find a deviation. Then there is a physics beyond the present one. I say of the new physics in advance exactly what I say of the present physics. The new physics is a description of comparisons, and so the new physics has the six intrinsics, of which symmetry and continuity are compounds, and so symmetry and continuity cannot both be perfected in the new physics. A deviation from quantum mechanics would be a new theory, but the new theory would be neither deterministic nor superdeterministic, because no comparison can instantiate (be an instance of) a deterministic or a superdeterministic theory.

So the argument against superdeterminism depends only on the Incommensuration Theorem. The argument against faster-than-light signaling depends only on the identification of c, the speed of light, as the macroscopic domain boundary. Neither argument depends on quantum mechanics. The conclusions of the two arguments are conditions that any formalism must satisfy, and not consequences of a particular formalism.

Why the Argument Cannot Be Escaped

A reader who wishes to keep superdeterminism must deny either the Root Tautology or the Incommensuration Theorem. The Root Tautology is the recognition that interaction, comparison, and relation are one act. The Incommensuration Theorem says that symmetry and continuity cannot both be perfected at once. Neither denial can be made without comparing, because to dispute the Root Tautology or the theorem a person must compare, and comparison has the structure that the Root Tautology and the theorem state. In each respect in which a comparison has a verdict, sameness and difference are inseparable. Content and context are distinct and inseparable. No one can deny that sameness and difference are inseparable, or that content and context are distinct and inseparable, without using both facts in the denial. No one can accept both the Root Tautology and the theorem and still keep superdeterminism, because superdeterminism is nothing other than the demand for the conjunction that the theorem forbids, symmetry and continuity perfected, extended to the observer.

VIII. Summary

The central claim of this essay is that superdeterminism is structurally excluded. The central claim is a structural exclusion: a claim that says what physics will not find, in advance of any experiment. My claim that superdeterminism is a category error across the triple of choice, change, and causality is a claim of the same kind. I read Quantum Mechanics and General Relativity as the two partial descriptions, and I give a reading of the circularity in the standard position. Both readings are readings of known physics. In this essay I deny only that regularity is total and that the residual is empty.

Superdeterminism is structurally unreachable. Superdeterminism requires the conjunction of symmetry and continuity perfected, which is what determinism requires, and the Incommensuration Theorem says that

no comparison can support that conjunction. In superdeterminism the demand is then extended to the observer, and the extended demand requires something further: that choice be causality, that the transcendent be the omniscient, and that the residual the theorem requires be empty. The further requirement is a claim across a boundary that, as the axioms state, cannot be crossed, and not a stronger claim of the same kind. So the further requirement fails as a category error before it can fail as a hypothesis.

Hossenfelder's proposal is right on more points than its critics usually allow, and I affirm each of the following points. Time has a direction. Quantum mechanics is not the final description. The standard account of the light-speed limit is circular. But each point, followed through, tells against the conclusion that the proposal draws from the point. Directed time requires that not everything is fixed. Quantum mechanics is partial because quantum mechanics is one of two survivors, and not because there is a deterministic floor (a deterministic theory) beneath quantum mechanics. And the circle is broken by grounding the light-speed boundary in comparison, where the boundary no longer needs a formalism to support it, and not by denying that the boundary is a boundary.

The universe is a process, lawful and open at once, and the universe is open in exactly the measure that the Incommensuration Theorem requires for anything to be compared at all. The universe is not a block in which the label "earlier" is a convention. The arrow of time is real. Hard randomness is real. Subjectivity is real. The arrow of time, hard randomness, and subjectivity are inseparable. Superdeterminism is the attempt to have the first, the arrow of time, while denying the second, hard randomness, and to have the arrow while denying hard randomness is the one thing the structure of the real does not permit.

KEY CONCEPTS IN THIS ESSAY

- **Superdeterminism**: determinism extended to the choices of measurement settings, so that setting and particle state share a common causal ancestry; excluded a fortiori by the argument against determinism, and additionally a category error.
- **Statistical independence**: the assumption in Bell's theorem that the settings are uncorrelated with whatever hidden state the particles carry; the assumption superdeterminism denies.
- **A fortiori exclusion**: what cannot be had for the particles cannot be had for the particles, the apparatus, and the experimenter together; a forbidden conjunction is not made available by enlarging its domain.
- **Choice, change, causality**: the foundational triple of the real; choice transcendent, change immanent, causality omniscient; distinct, inseparable, and non-interchangeable.
- **Category error**: the attempted reduction of one modality to another across a boundary the third axiom holds impassable; superdeterminism is the reduction of choice to causality.
- **The residual**: the domain in which the outcome is not fixed by the structural pattern; required by the theorem in any world admitting comparison; named choice; not epistemic ignorance.
- **The arrow of time**: directed time as asymmetry, the survivor that pairs with continuity; bound with hard randomness and subjectivity; unavailable to a block universe.
- **The circularity**: the standard position's grounding of the light-speed boundary in quantum fundamentality and quantum fundamentality in the boundary; dissolved by grounding the boundary in comparison instead.
- **Conjugate descriptions**: quantum mechanics as symmetry with discontinuity applied to the transcendent domain, general relativity as continuity with asymmetry applied to the omniscient domain; the two survivors, neither beneath the other.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.45-1 (distinct, inseparable, non-interchangeable); 1.85-4 (causality, change, and choice).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The essay on the binding of subjectivity, temporal direction, and hard randomness.

Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Bell, John S. *Speakable and Unspeakable in Quantum Mechanics.* 2nd ed. Cambridge: Cambridge University Press, 2004. The paper "Free Variables and Local Causality."

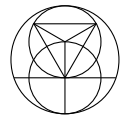
Hossenfelder, Sabine, and Tim Palmer. "Rethinking Superdeterminism." *Frontiers in Physics* 8 (2020): 139.

Hossenfelder, Sabine. "Superdeterminism: A Guide for the Perplexed." Preprint, 2020.

Handsteiner, Johannes, et al. "Cosmic Bell Test: Measurement Settings from Milky Way Stars." *Physical Review Letters* 118 (2017): 060401.

Rauch, Dominik, et al. "Cosmic Bell Test Using Random Measurement Settings from High-Redshift Quasars." *Physical Review Letters* 121 (2018): 080403.

The BIG Bell Test Collaboration. "Challenging Local Realism with Human Choices." *Nature* 557 (2018): 212–216.



Essay 10

Causation, Connectivity, and the Domain Boundary of Comparison

Why the Speed of Light Is Not a Speed,
and Why Faster-Than-Light Signaling Is Malformed

ABSTRACT

When someone asks whether a signal can travel faster than light, the person assumes that the speed of light is a limit on velocity, imposed on signals that travel through a space that is already there. In this essay I argue that the assumption is mistaken. The speed of light is not, at root, the speed of any one thing. The speed of light is the macroscopic boundary of the domain of comparison, the whole range within which one thing can be compared with another, and so the speed of light is the outer limit of causal connectivity: the outer limit of which events can affect which other events. Space is constituted by causal relations. Space is not a container through which causal signals happen to pass. Causal relations are comparisons, so the boundaries of space are the boundaries of comparability. The lightcone of an event is the set of all events that can be causally connected to that event. The lightcone is therefore the primary structure, the shape of causal relatedness itself, and not a consequence of a speed limit. The constant c, the speed of light, is the factor by which the shape of the lightcone is distributed between the temporal and the spatial aspects of the lightcone. A request to signal faster than light is a request to make a comparison beyond the boundary of comparability. A request to compare beyond comparability fails by its own formulation, in the way

that a request to travel beyond the antipode of a sphere (the point of the sphere farthest from where one stands) fails by its own formulation. I build the argument of this essay on the Root Tautology: interaction, comparison and relation are one act. The argument does not depend on quantum mechanics, on the no-signaling result within quantum mechanics, or on any particular formalism. A formalism is a particular mathematical scheme of physics. I name the two boundaries of the domain, the microscopic and the macroscopic. I also say what lies outside the scope of the argument, including travel within the lightcone and cosmological recession. Cosmological recession is the moving apart of distant galaxies as the universe expands. And I reply to the suggestion that faster-than-light communication explains the silence of the sky: the fact that we hear nothing from other civilizations.

Note on framework. This essay depends on the Introduction to this volume for the six intrinsics, the Incommensuration Theorem, the three axioms, and the modal alignment, and on the essay on measurement as interaction in Part I. This essay is the companion to the essay on superdeterminism, which immediately precedes it. The two essays are about two halves of one proposal that is often made in public discussion of superdeterminism. The essay on superdeterminism is about the half of the proposal that says a deterministic theory deeper than quantum mechanics fixes the settings of the measuring devices along with everything else. This essay is about the other half, which says that departures of the deeper theory from quantum mechanics might allow signals faster than light. I develop both boundaries further in the essays on the three horizons and on the domain constants, in Part IV. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Standard Framing

In ordinary language, and in most of what is written for the public, the speed of light is presented as a speed limit. Nothing can travel faster than light. No object, signal or information can exceed the speed of light. The figure usually given for the speed of light is a little under three hundred thousand kilometers per second, or exactly 299,792,458 meters per second by the convention that now defines the meter in terms of the speed of light. I quote the figure only to describe the speed of light. Nothing in this essay depends on the figure. Relativity says three things more. A massive body, a body that has mass, would need an unbounded quantity of energy to reach the speed of light. Durations lengthen and lengths shorten as a body approaches the speed of light. And no additional push, however great, carries a massive object past the speed of light.

Calling the speed of light a speed limit is not exactly wrong, but the speed-limit framing is misleading, because people who accept the framing are led to a question that does not deserve the effort spent on the question. The speed-limit framing comes with a picture in which space is a stage, objects are the actors on the stage, and the speed of light is a rule that limits how fast the actors may move about. Once a person holds the picture of the stage, the person naturally asks whether the rule might be broken. Can we find a loophole, a shortcut or a channel that the speed rule does not cover?

The answer is no. There is no way past the speed of light because the speed-limit framing is wrong, and not because the rule is especially strict. The speed of light is not a rule, and space is not a stage. There is only the structure of connectivity that the word “space” names: the structure of which events can affect which other events. The speed of light is a feature of the structure of connectivity, and not a restriction laid upon the struc-

ture. In the rest of this essay I describe the structure of connectivity precisely enough that anyone can see, from the question of signaling past the limit itself, why the answer is no.

II. Causation as a Form of Comparison

I begin from the Root Tautology: interaction, comparison and relation are one act, named three ways. I develop the Root Tautology in the Introduction to this volume, where I also state the six intrinsics that follow from the Root Tautology. The six intrinsics are the six features that belong to every act of comparison by its nature, such as content and context. In this essay I need only one consequence of the Root Tautology. If interaction is comparison, then the structure of comparison is the structure of interaction. Whatever is intrinsic to comparison is intrinsic to every physical event, because a physical event is an interaction, and a measurement is an interaction described as one in which the comparison is recorded. Whatever limit applies to comparison as such applies to every physical event as such.

Causation is a specific kind of interaction. Causation is the interaction in which the pattern of relations between events is consistent and directed: causes precede effects, similar causes are followed by similar effects, and the causal relation does not run the other way. In the modal alignment that I hold fixed in this book, which the Introduction sets out, causality has the nature of the omniscient. The omniscient is the mode of structure, of what holds regardless of who looks. Causality is the repeatable, the structural and the shareable: what an observer sees when the same kind of thing is followed by the same kind of thing across many contexts. Causality is a pattern read from within time, which is why causality is asymmetric (directed). And causality is a pattern, which is why causality is lawful. I argued in the essay on determinism and causality, in Part I,

that causality in this sense is what science establishes. I also argued that causality is not the same as determinism. In this essay I take causality as the thing whose reach is in question.

If interaction is comparison, then causation is a form of comparison. And if causation is a form of comparison, then the structure of comparison constrains the structure of causation. Wherever comparison has a boundary, causation has the same boundary, and the boundary is the edge of what causation is and not a restriction imposed on causation from outside.

III. What Space Is

Consider two events, and call them A and B. The standard framing is the speed-limit framing of Section I. In the standard framing, A and B occupy positions in a space that is already there. The question whether A can affect B is then the question whether a signal can get from the position of A to the position of B within the constraints of the speed limit. In the standard framing, space comes first, and events are embedded in space. Causal relations are layered on top of the events, and then the speed rule cuts away every causal relation between two events that would need a signal faster than light to connect them.

On my account the order of the standard framing is reversed.

Two events are related if and only if one of the two events can affect the other event. By the Root Tautology, to say that one event can affect another is to say that a comparison can be made between the two events, or that an interaction connects them. The word "space" names the set of all connections between related events: the total structure of which events can affect which other events. Space is the connectivity topology of causal relations, that is, the pattern of which events are causally connected to which other events. Space is not a container that exists prior to the events it holds. In the fixed modal alignment, space is the omniscient context. A context is the frame of a comparison. Space is the pattern that holds across

different contexts, the structure in which what is here can be compared with what is there. Time, by contrast, is the immanent context, where the immanent is the mode of process: time is the process in which the comparison is made, the change through which anything is here rather than there. The first axiom says that the immanent is more fundamental than the omniscient and/or the transcendent, where the transcendent is the mode of the generative, of what makes a domain possible. Time is immanent and space is omniscient, so on this account the temporal is prior to the spatial, and I take up the priority of the temporal in the essay on the arrow of time. What this essay needs is that space is a structure of relations, that the relations are causal, and that causal relations are comparisons.

I want to insist that the claim that space is a structure of causal relations is not a radical proposal brought in from outside physics. The claim is the content of general relativity (what general relativity says), stated without the picture of space as a container. In general relativity, spacetime is a dynamic structure, determined by the distribution of matter and energy, and not a fixed background, and spacetime has no properties apart from the relations among events. In general relativity the geometry is the physics, and the curvature of spacetime is the gravitation. Nothing exists in general relativity that could be called space apart from the relations among events that constitute space. There are well-known results within general relativity to the effect that the causal structure alone, the pattern of which events can reach which, already fixes the topology, the pattern of which events lie near which. I take the well-known results seriously and follow the results back to comparison. If space is constituted by causal relations, and causal relations are comparisons, then space is constituted by comparison. So the boundaries of space are the boundaries of comparability.

IV. The Two Boundaries of the Domain

Comparison has structural limits. The limits are intrinsic to what comparison is, and are not technological. There are two structural limits of comparison, and I named both in the Introduction.

The microscopic boundary is marked by Planck's constant, named for the physicist Max Planck. Below the scale that Planck's constant sets for a given energy, no comparison can be made finer. At the scale of Planck's constant the content of a comparison, what is being compared, becomes granular: the content comes as discrete eigenvalues (definite values that a measurement can return), quantized charges and integer-valued quantum numbers. Granular content is what one finds when comparison is carried to its lower bound. I develop granular content as the physical face of quantum indeterminacy in the essay on the microscopic boundary, in Part IV. Symmetry is sameness of content across difference of context. Discontinuity is difference of content within sameness of context. The Incommensuration Theorem says that symmetry and continuity cannot both be applied absolutely, while symmetry and discontinuity can both be applied absolutely. To apply a compound absolutely is to hold it exactly, at the foundation of a description. So, in the terms of the Incommensuration Theorem, granular content is what one finds where symmetry is asked for absolutely: discontinuity.

The macroscopic boundary is marked by the speed of light. Beyond the reach that the speed of light sets for a given elapsed time, no comparison can be made at all. The cosmological horizon is the macroscopic counterpart of the microscopic limit. The cosmological horizon is the surface beyond which the structure of comparison does not extend from here, from the place and time where we are. What lies past the cosmological horizon is out of comparison because nothing from past the horizon has arrived here or can arrive here, and not because what lies past the horizon is far away. I place the cosmological horizon beside two other horizons in

the essay on the three horizons, in Part IV. The two other horizons are the microscopic limit that Planck's constant marks and the mesoscopic horizon of the knowing self, past which the self cannot see itself. I develop Planck's constant and the speed of light as the pair of constants that bounds every domain in the essay on domain constants.

Taken together, the microscopic boundary and the macroscopic boundary define the domain of comparison. Neither boundary is a constraint imposed on a space that is already there. The two boundaries are the edges of the arena within which comparison, and therefore interaction, can occur. Physics is the structure that exists between the two boundaries. Physics does not happen in a space that extends beyond the two boundaries and is merely cut off at them. Planck's constant is the quantum of action, the minimum package of process. The speed of light is the maximum rate of causal connection, the outer reach of process. Together Planck's constant and the speed of light bracket the domain of comparison, from the finest grain to the farthest reach. Both constants are properties of comparison itself. Neither constant is a property of the things being compared.

V. The Lightcone as Primary

In relativity the lightcone of an event is the set of all events that can be causally connected to the event. The forward cone contains every event that the given event can affect. The backward cone contains every event that can affect the given event. Where an event lies outside both cones of a given event, the two events are spacelike separated: neither event can affect the other, and no signal passes between the two events.

In the standard framing, spacelike separation is a consequence of the speed limit. Two events are spacelike separated because a signal between the two events would have to exceed the speed limit, and no signal can. In the standard framing the cone is secondary: take the speed limit, apply the limit to every possible path, and the cone is what remains.

On my account the order is reversed. The cone is primary, and is not obtained from the speed limit. The cone is the structure of causal relatedness, which is to say the structure of which comparisons can be made from here.

The general relativity notion of causality is a very perfected notion of causality. "Perfected" has the sense that the word has in the Incommensuration Theorem: carried all the way. In general relativity there is a cone at each event: everything inside the cone can be reached from the event, nothing outside the cone can be reached from the event, and the cone points one way. The cone at each event is causation in its own character, unbroken and one-way, and a structure that is unbroken and one-way is continuity with asymmetry, which under the Incommensuration Theorem can be carried all the way. General relativity is continuity with asymmetry carried all the way, that is, applied absolutely. Suppose someone tries to think of causality in a way that is not in some sense derived from the general relativity notion of causality. Then that person probably has an inconsistent notion of causality.

Two events are spacelike separated because there is no causal connection between them. The reason is not that a signal between the two events would have to be too fast. Neither event is in the domain of the other event's comparisons, and no interaction of any kind connects the two events. No information passes between the two events, because there is no connection between the two events to carry the information. The reason is not that a rule forbids the passage of information.

On the understanding of the lightcone as primary, the speed of light is not, at root, the velocity of anything in particular. The speed of light is the greatest speed at which any signal can pass, and the speed of light is also the conversion factor between the temporal and the spatial aspects of the causal connectivity structure. A conversion factor turns a measure of one kind into a measure of another kind, the way the number of centimeters in an inch turns a length in inches into a length in centimeters. The speed of light turns a span of time into the span of space that the edge of the cone

reaches in that time. The speed of light is the constant that mediates between the omniscient context, which is space, and the immanent context, which is time. The speed of light describes the geometry of the domain: how the boundary is shaped, that is, how the macroscopic limit of comparison is distributed between the one temporal direction and the several spatial directions. Light happens to travel at the speed of light, which is a fact about light: light is the kind of thing whose connections lie on the boundary rather than inside the boundary. But the speed at which light happens to travel is not the reason the boundary of the domain is where it is.

On the Word "Constant"

People sometimes ask, as a puzzle, why the speed of light should be the same for every observer when the speed of everything else differs from one observer to another. On the reading that I give in this essay, there is no puzzle. The speeds of things are ratios of content within the domain, such as a distance covered divided by the time taken, and the speeds of things differ from context to context, which is what one expects of content. The speed of light is the shape of the edge of the domain of comparison, and not a ratio within the domain. The edge is the same from everywhere, because the edge is not a thing in the domain at all. The edge is a property of comparison, and comparison is what every observer is doing. The invariance of the speed of light is what it means for a boundary to be a boundary. The invariance is not an additional fact that a theory had to accommodate. I offer this account of the invariance as a reading of a known result, not as a replacement for relativity, the theory that established it.

VI. The Category Error: Beyond the Antipode

The speed of light is the edge of the domain of comparison and not a limit on speed, so to ask whether one can signal faster than light is a category error, a mistake that treats a thing of one kind as a thing of another kind. I want to say exactly what kind of category error the question is.

Whoever asks whether one can signal faster than light treats the speed of light as a constraint on motion through space. But the speed of light is the shape of the domain of comparison, the domain within which motion is defined. The speed of light is not a constraint on motion. A constraint is something that could in principle be otherwise: a rule that might be relaxed, a wall that might be climbed, a limit that better instruments might exceed. The edge of a domain is none of those three things: the edge of a domain is what makes the domain the domain it is, and not a rule about what is in the domain.

An analogy shows the kind of category error. Consider the surface of a sphere, and a person standing at one point of the surface. The person may ask: can I travel to a point on the surface that is farther from me than the antipode? The antipode is the point of the surface directly opposite the person. The answer is no, because on the surface of a sphere the antipode is the farthest point there is, and not because some rule forbids a traveler to go beyond the antipode. At the antipode, "beyond" is not defined, because the surface does not extend to any point farther away than the antipode. The question is malformed, not hard, and the person who asks the question has not yet understood what kind of thing a sphere is. In the analogy the surface of the sphere stands for the domain of comparison, the antipode stands for the edge of the domain, and travel beyond the antipode stands for a signal faster than light.

Signaling faster than light is the causal counterpart of traveling beyond the antipode. Signaling faster than light is precluded by the structure of the domain of comparison, and not forbidden by a rule. There is no

"there" to signal to. Events outside the cone of an event are outside the causal domain of the event, and so the events outside the cone are not far-away places that might be reached with better technology. In the sense that matters to this argument, a place is a position in the connectivity structure. Events outside the cone of a given event have no position in the connectivity structure of the given event, and so, from the given event, the events outside its cone are not places at all, not even places that are inaccessible.

The argument of this essay now has the same shape as the argument of the essay on superdeterminism. Superdeterminism is the view that the experimenter's choice of what to measure was fixed in advance, together with what the particles do. I argued in the essay on superdeterminism that the proposal to determine the observer's choice is a claim across a modal boundary, the boundary between two modalities: choice has the nature of the transcendent, and causality has the nature of the omniscient. A claim across a modal boundary treats a thing of one modality as a thing of another modality. So the proposal to determine the observer's choice is a category error rather than a hypothesis, and not a stronger claim of the same kind as determinism. The proposal to signal past the boundary has the same shape, because the proposal to signal past the boundary is the claim to compare beyond comparison, and not a stronger claim than the claim to signal fast. A comparison beyond the domain of comparison is not a comparison. A causal connection outside the causal structure is not a connection. As a concept, a causal connection outside the causal structure fails structurally, and not empirically. The concept fails before there is anything for an experiment to test.

VII. Independence from Quantum Mechanics

Physicists usually argue against faster-than-light signaling from the no-communication theorem of quantum mechanics. The no-communication theorem says that one cannot use an entangled pair to send informa-

tion, where an entangled pair is a pair of particles whose measured properties are correlated however far apart the particles are. The reason one cannot send information is that the statistics of a measurement on one member of the pair do not depend on which measurement is made on the other member. The correlations between the two members are real, and the correlations exceed what any local causal account allows. I describe the correlations in the essay on Bell's theorem, in Part II. The physicist John Bell proved Bell's theorem, which shows that the correlations of entangled pairs exceed what any local causal account allows. But no one can modulate the correlations from a distance (change the correlations at will to carry a message), and so the correlations carry nothing.

The no-communication argument is correct, but the argument is not fundamental, and the reason is worth seeing. The no-communication theorem is a result within a specific formalism, the formalism of quantum mechanics. One can imagine proposing a different formalism: a modification of quantum mechanics, a hidden-variables theory, or a regime in which the standard predictions fail. A hidden variable is a quantity beyond the quantities of quantum mechanics that would fix each outcome in advance. One can then ask whether the no-signaling result survives the change of formalism. I examined exactly the strategy of changing the formalism in the preceding essay, on superdeterminism, where the hope was that a deeper deterministic theory might permit deviations from quantum mechanics, and that the deviations might open a channel for signals faster than light. Whatever one thinks of the deeper theory, the hope depends on the assumption that the boundary is held in place by the formalism, so that changing the formalism might move the boundary.

The argument of this essay does not depend on any formalism, because the argument does not use the no-signaling result, the formalism of entanglement or the structure of the wavefunction. The argument depends only on three things: that interaction is comparison, that comparison has structural limits, and that the speed of light marks the macroscopic limit. Even if quantum mechanics were modified or replaced, the domain boundary would remain, because the domain boundary was never a

quantum-mechanical result. No theory, quantum or otherwise, can extend comparison beyond the boundary of comparability for the same reason that no theory can make a comparison that is not a comparison. The physics that we have is consistent with the boundary. But the boundary does not rest on the physics that we have.

A related proposal says that faster-than-light signaling could be made consistent if the universe has a preferred temporal direction that prevents the construction of causal loops, chains of signals by which an effect would come back to act on its own cause. I agree that the universe has a preferred temporal direction: on this account the temporal is prior to the spatial. I argue in the essay on the arrow of time that the direction of time is structural before it is thermodynamic, that is, before it is the direction in which heat spreads and disorder grows. But the agreement gives no way to signal faster than light. The agreement shows only that the causal structure is directed: that the cone has an arrow. The arrow does not enlarge the cone. A preferred temporal direction says which half of the cone is the future and which half is the past. A preferred temporal direction does not extend either half of the cone to include what is spacelike separated from the event at the tip of the cone. Directed time and bounded causal connectivity are features of the same structure, and not alternatives between which one must choose, so neither feature can be used to buy relief from the other.

VIII. What Is Not Excluded

A reader can easily mistake the argument of this essay for a larger argument, so I want to mark carefully where the argument ends.

The argument shows nothing against interstellar travel. What the argument shows to be impossible is signaling that exceeds the causal domain boundary. Travel within the cone remains structurally permitted, however slow the travel is relative to popular aspiration. I take no position at all on whether interstellar travel is technologically feasible. A body can go to any

event in its forward cone, and given time the forward cone of a body contains a great deal. A body cannot arrive somewhere that is not in its forward cone, and the body's inability to arrive outside its cone is a description of where "somewhere" is, and not a limitation on the body.

The argument also shows nothing against the phenomena of the large-scale geometry that are sometimes described as superluminal, that is, faster than light. The phenomena are the expansion of the universe and the recession of distant galaxies at effective rates that, computed in a natural way, exceed the speed of light. The expansion and the recession are features of the connectivity structure as a whole: of how the domain is shaped at its farthest reach. The expansion and the recession are neither signaling nor causal connection. The expansion and the recession are the reason the cosmological horizon is where it is. Nothing in the expansion or the recession compares anything across the boundary.

The argument also shows nothing against the correlations of entangled systems, and the correlations of entangled systems are real. I read entangled correlations in the essay on Bell's theorem as the failure of lawfulness and locality to be had together absolutely. Lawfulness is the assumption that physical law is the same in every place and time, a case of symmetry, and locality is the assumption that no influence crosses a distance in zero time, a case of continuity. The Incommensuration Theorem says that symmetry and continuity cannot both be perfected together. So, when lawfulness and locality fail to be had together absolutely, the failure is an instance of the Incommensuration Theorem. But a correlation is not a connection: nothing passes between the entangled systems, and the argument of this essay concerns what can pass.

IX. The Fermi Paradox and the Wrong Channel

The suggestion that prompted this essay deserves a specific reply. The physicist Enrico Fermi asked why, if other civilizations exist, we see no sign of them. Physicists call Fermi's question the Fermi paradox. In public

discussion of superdeterminism some have proposed, as an application of the superdeterministic program, that other civilizations may communicate faster than light. On the proposal, faster-than-light communication would explain the silence of the sky: we hear nothing because we are listening on the wrong channel.

If the argument of this essay is correct, no civilization communicates faster than light, because no civilization can. The limit on causal connection is structural, not technological. So the limit is not one that a more advanced technology might have surpassed. The limit applies to any being, in any universe, that interacts with anything else, because interaction is comparison, and comparison has the boundaries that the Incommensuration Theorem and the domain of comparison describe. Suppose a civilization has understood physics better than we have. Then the civilization has understood, among other things, what kind of thing the boundary is, and the civilization has not found a way past the boundary, because there is nothing past the boundary for a way to lead to.

Because no civilization communicates faster than light, the silence of the sky requires some other explanation. There is no shortage of candidates. I do not offer one of the other explanations in this essay. What I do in this essay is eliminate the explanation by faster-than-light communication. I would add only that the proposal has a shape that I have now met twice in this book: the attempt to get outside a structure by means of the same structure. In superdeterminism the attempt is to determine the chooser by causality, and in faster-than-light signaling the attempt is to connect the unconnected by connection. Each time, the attempt fails because of how the attempt is formulated, and not because of any evidence against the attempt.

> **On the Kind of Impossibility Claimed**
>
> In this essay I argue for an impossibility that is structural, not empirical and not logical. The impossibility is not logical, because a formalism in which some quantity exceeds c is a perfectly consistent object. Physicists have written down several formalisms in which some quantity exceeds c.

> The impossibility is not empirical: I cite no experiment and none is needed, though every experiment is consistent with the impossibility. The impossibility is structural: the request to signal past the boundary is the request to compare beyond comparison, and there is no content to the request once the terms of the request are understood. The conclusion depends on the identification of space with the connectivity topology of causal relations, and on the Root Tautology beneath that identification. The conclusion does not depend on any particular physics. The physics already says what I read the physics as saying.

X. Summary

The central claim of this essay is that no signal can cross the macroscopic boundary of comparison. The central claim is a structural exclusion: it says what physics will not find, and it says so before looking. The claim that faster-than-light signaling is malformed, and not merely impossible, is a claim of the same kind. I give three readings of known results in this essay: the reading of the lightcone as primary, the reading of the speed of light as the conversion factor between the temporal and spatial aspects of connectivity, and the reading of the invariance of the speed of light as the invariance of an edge. Each reading states the structural reason why the known result is true. The number of the speed of light expresses a unit, fixed by the definition of the meter. What I read in this essay is the boundary.

The speed of light is not, at root, the speed of any one thing. The speed of light is the macroscopic boundary of the domain of comparison.

Space is the structure of causal connectivity, the totality of relations that join events to one another. Space is not a container. Since the relations that join events are comparisons, the boundaries of space are the boundaries of comparability. The lightcone is the shape of the causal domain itself,

and not a speed limit applied to signals moving through a container. The constant c is how the shape of the causal domain is shared between the one direction of time and the directions of space.

Signaling faster than light would mean making a comparison beyond the boundary of comparability. The concept of a signal faster than light is structurally incoherent, and not empirically difficult. The trouble is that the request to signal faster than light is malformed, as the request to travel beyond the antipode is malformed, and not that we lack the technology. One cannot interact with an event that is outside the domain of interaction. One cannot compare beyond the reach of comparison.

The argument of this essay does not depend on quantum mechanics, on special relativity as a set of postulates, or on any particular formalism. The argument depends on the structure of comparison, which is the structure of interaction, which is the structure of physics. The boundary is the edge of the domain, and not a wall. Beyond the edge there is not forbidden territory. For a comparer here, "beyond" is not defined at the edge: the edge is a limit of comparison, and the limit that the Incommensuration Theorem draws is "the curvature of the field itself, rather than a wall at the edge of an otherwise open field" (*Incommensuration; The Theorem and the Three Axioms*, Chapter 6, Section XI). No comparison made from here reaches past the edge, no causal connection crosses the edge, and no finding comes through the edge. The lightcone is the shape of what it means for anything to happen at all. The universe is not a cage with the lightcone for its bars.

KEY CONCEPTS IN THIS ESSAY

- **Root Tautology**: interaction, comparison, and relation are one act, named three ways; the premise from which the structure of comparison is carried into physics.
- **Causation as comparison**: causation as the directed, consistent form of interaction; omniscient in the fixed alignment; bounded wherever comparison is bounded.

- **Space as connectivity topology**: space constituted by the structure of causal relations, not a container in which causal relations are embedded; the omniscient context, with time as the immanent context.
- **The two boundaries**: Planck's constant as the microscopic edge of the domain of comparison, below which nothing finer is compared; the speed of light as the macroscopic edge, beyond which nothing is compared at all; properties of comparison, not of things.
- **The lightcone as primary**: the set of events causally connected to a given event, taken as the basic structure rather than as obtained from a speed limit; the shape of causal relatedness.
- **c as conversion factor**: the speed of light as the factor distributing the macroscopic boundary between its temporal and spatial aspects; the geometry of the domain, not the velocity of a thing.
- **The antipode**: the analogy for the malformed question; there is no farther than the farthest point, and for the boundary of comparison "beyond" is not defined.
- **Category error**: treating the speed of light as a constraint on motion through space rather than as the edge of the domain within which space, motion, and speed are defined.
- **Directed time**: the preferred temporal direction of the causal structure; directed time says which half of the cone is future and which past, and directed time does not enlarge the cone.
- **What is not excluded**: travel within the cone, cosmological recession and expansion, and entangled correlations; none of the three compares anything across the boundary of comparison.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.43-6 (measurement, observation, perception, interaction); 1.85-4 (causality, change, and choice); 1.85-8 (the six measures, space and time among them).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six measures.

Einstein, Albert. "Zur Elektrodynamik bewegter Körper." *Annalen der Physik* 17 (1905): 891–921.

Minkowski, Hermann. "Raum und Zeit." *Physikalische Zeitschrift* 10 (1909): 104–111.

Hawking, S. W., and G. F. R. Ellis. *The Large Scale Structure of Space-Time.* Cambridge: Cambridge University Press, 1973.

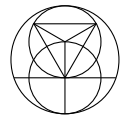
Malament, David B. "The Class of Continuous Timelike Curves Determines the Topology of Spacetime." *Journal of Mathematical Physics* 18, no. 7 (1977): 1399–1404.

Ghirardi, G. C., A. Rimini, and T. Weber. "A General Argument against Superluminal Transmission through the Quantum Mechanical Measurement Process." *Lettere al Nuovo Cimento* 27, no. 10 (1980): 293–298.

Davis, Tamara M., and Charles H. Lineweaver. "Expanding Confusion: Common Misconceptions of Cosmological Horizons and the Superluminal Expansion of the Universe." *Publications of the Astronomical Society of Australia* 21, no. 1 (2004): 97–109.

Hossenfelder, Sabine, and Tim Palmer. "Rethinking Superdeterminism." *Frontiers in Physics* 8 (2020): 139.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.



Essay 11

The Structural Arrow of Time

A Non-Entropic Temporal Asymmetry
from the Intrinsics of Comparison

ABSTRACT

On the standard account of the arrow of time, the direction of time comes from entropy, a measure of the disorder of a system. On the standard account, the second law of thermodynamics supplies the asymmetry between past and future, because the fundamental equations of physics are time-reversal symmetric, and so the equations supply no asymmetry. In this essay I argue that there is a deeper arrow: a non-entropic temporal asymmetry that the Incommensuration Theorem structurally requires. Time-reversal symmetry is a symmetry, and a symmetry of the laws guarantees that the reverse of a lawful process is lawful. A symmetry of the laws does not guarantee that the reverse is faithful, that is, that the reverse retraces the original process exactly. Faithful reversal requires a continuously specified state. The conjunction of perfected symmetry with perfected continuity is exactly the conjunction that the Incommensuration Theorem forbids. Perfect time-reversal is therefore precluded, and the preclusion depends on no entropy, no boundary condition, no Past Hypothesis (the assumption that the universe began in a state of extraordinarily low entropy) and no particular formalism. I argue that the structural arrow is more fundamental than the thermodynamic arrow, and I identify the structural arrow with the precedence of the second axiom of the metaphysics (Axiom II, which Section VI quotes), applied to

the physical domain. I tie the structural arrow to the theorem of the mathematicians John Conway and Simon Kochen, keeping the condition that Conway and Kochen state for their theorem. I read the observed violation of CP symmetry and of T symmetry as consistent with the argument, where T is time reversal and CP is the exchange of every particle for its antiparticle combined with a mirror reflection. I state plainly what the argument does not establish: the magnitude of any asymmetry, the low entropy of the early universe, or the second law itself.

Note on framework. This essay depends on the Introduction to this volume, where I state the Incommensuration Theorem in full. This essay also depends on the essay on determinism and causality, earlier in this volume, where I apply the theorem to the possibility of determinism. This essay refers as well to my companion discussion, in *Accessing the Real*, of the binding triple: hard randomness, the arrow of time and subjectivity, each of which requires the other two. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Problem of Time's Arrow

The fundamental equations of physics are very nearly all time-reversal symmetric. Newton's laws of motion are time-reversal symmetric, and so are Maxwell's equations of electromagnetism, the Schrödinger equation and Einstein's field equations: each of those equations admits solutions that run equally well forward and backward. If a process is possible under the law, the time-reverse of that process is possible under the same law, and so nothing in the form of the equations distinguishes past from future.

Yet the world is manifestly asymmetric in time. Eggs break and do not unbreak. Heat flows from hot to cold. Memory records the past and not the future. Causes precede effects. The experience of temporal direction is among the most immediate and most universal features of anything we would call reality.

The problem of time's arrow is why the world is asymmetric in time when the equations are not. The standard answer to the problem is thermodynamic: on the standard account, the arrow of time is the direction in which entropy increases. Entropy counts the ways in which the parts of a system can be arranged without changing how the system looks as a whole, and a disordered system has more such arrangements than an ordered system has. The second law of thermodynamics says that the entropy of an isolated system does not decrease. On the standard account, the second law supplies the asymmetry that the equations lack. But the second law is statistical: the second law describes the overwhelmingly probable behavior of very large ensembles (collections of very many particles), and is not a strict rule governing each event. The second law also requires a boundary condition: an assumption about how things stood at one end of the history being described. The statistical argument needs the assumption that the universe began in a state of extraordinarily low entropy. Without the assumption of a low-entropy beginning, the statistical argument is itself symmetric: from any given moment, the statistical argument predicts increasing entropy in both temporal directions. The assumption of a low-entropy beginning is the Past Hypothesis. The philosopher of physics David Albert has argued, in his book *Time and Chance*, that the Past Hypothesis should be admitted as a fundamental law in its own right, precisely because nothing else in physics supplies the Past Hypothesis.

Because the second law needs the Past Hypothesis, the entropic arrow depends on a contingent fact about initial conditions, and philosophers and physicists alike have been troubled, and rightly, that the arrow of time should depend on a fact that could have been otherwise. Why should the direction of time depend on a cosmological accident, when the direction

of time is so basic to experience? The philosopher Huw Price has pressed the point from the other side, the side of the observer, in his book *Time's Arrow and Archimedes' Point*. Price argues that our sense of a direction to time may be a parochial artifact of our own position within time. On Price's view, the unbiased view is the view from nowhen: the Archimedean point outside time, from which no direction of time is privileged. I accept the force of both worries, and I argue that both worries are answered at a level more basic than thermodynamics. The arrow of time depends on the structure of comparison itself, and not on entropy. By comparison I mean the act that the Introduction shows to be one with interaction.

II. Symmetry, Continuity, and the Theorem

I state the Incommensuration Theorem in full in the Introduction to this volume. In this essay I restate the theorem only in the form that my argument needs. Comparison has six intrinsics, six features that belong to comparison by its nature: sameness and difference, content and context, and the subjective and the objective. Content is what is being compared, and context is the frame of the comparison. When sameness and difference are applied to content and context, the result is four secondary compounds. Continuity is sameness of content within sameness of context. Discontinuity is difference of content within sameness of context. Symmetry is sameness of content across difference of context. Asymmetry is difference of content across difference of context.

The Incommensuration Theorem says that when any two of the four compounds (continuity, discontinuity, symmetry and asymmetry) are applied absolutely and together, two conjunctions are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two conjunctions survive as valid absolute conjunctions: continuity with asymmetry, and symmetry with discontinuity. To be applied absolutely is to hold exactly, at the foundation of a description. The qualifier "applied absolutely" is part of

the theorem and is never dropped. Within any finite domain, symmetry and continuity co-occur to finite degree, but symmetry and continuity cannot both be perfected at once.

I use one modal alignment throughout this book, the alignment that the Introduction fixes, and in that alignment symmetry, continuity and interaction each have the nature of one of the three modalities: the immanent, the omniscient and the transcendent. The immanent is the mode of process, the omniscient is the mode of structure, and the transcendent is the mode of the generative. Symmetry is the omniscient compound: the structural, the repeatable, the shareable, the same content in every context. Continuity is the transcendent compound: the unbroken, the fully specified, the same content held without gap throughout a single context. Interaction is immanent: the processual, the here and now, the actual comparison in which symmetry and continuity are each encountered but neither is perfected. Aphorism 1.85-4 of my book *An Immanent Metaphysics* states that causality is omniscient, change immanent, choice transcendent. Time is the metric of change, and time belongs to the immanent. Later in this essay, where I ask what kind of thing the arrow of time is, I rely on time belonging to the immanent.

III. Lawful Reversal and Faithful Reversal

Time-reversal symmetry is a symmetry in exactly the sense defined in Section II: sameness of content across difference of context. Time-reversal symmetry means that the content of the physical laws remains the same when the temporal context is reversed, and in time-reversal symmetry the difference of context is the replacement of t, the time, with minus t. Time-reversal symmetry is the definition of symmetry applied to one particular difference of context, and not an analogy.

Perfect time-reversal symmetry would require that the reversal hold for every process, at every scale, in every context, without exception. In the standard account, physicists pass over a distinction between two

claims about reversal, and the two claims are different. The first claim is that the laws are symmetric: if a process is lawful, its time-reverse is lawful. The second claim is that the reversal is faithful: the time-reversed process traces back through exactly the states that the original process traversed, and the time-reversed process arrives at exactly the original condition. The first claim is about the form of the laws. The second claim is about the completeness of the state that the laws act upon.

Symmetry of the laws guarantees lawful reversal, but symmetry of the laws does not guarantee faithful reversal. Every aspect of the state must be captured in the specification that is reversed, if the reversal is to reproduce the original process. A degree of freedom is one of the independent quantities that together fix the state, such as the velocity of one particle. If even one degree of freedom is left unspecified, then the reversed dynamics can carry that degree of freedom somewhere other than where it came from, and the reversed process will not retrace the original. Faithful reversal requires a state with no gaps, no ambiguities and no unspecified residue.

Full specification of the state, with no gaps, is precisely continuity in the sense that the Incommensuration Theorem uses: sameness of content (the state being defined) within sameness of context, at every point and every scale, without interruption. Perfect time-reversal is reversal that is faithful and not merely lawful. So perfect time-reversal requires two things at once: the symmetry of the laws under reversal, and the continuity of the specification of the state. The symmetry of the laws under reversal and the continuity of the specification of the state, taken together, are the conjunction of symmetry with continuity, applied absolutely and together. The conjunction of symmetry with continuity is the conjunction that the Incommensuration Theorem forbids.

The steps so far in this section are the whole of the argument of this essay. I want to be clear about which step the argument depends on. The argument depends on one step, the bridge between lawfulness and faithfulness: faithful reversal requires a fully specified state, and in every other step I apply the Incommensuration Theorem.

Why the Bridge Is Invisible in the Formalism

Physicists usually overlook the step from symmetric laws to continuously specified states, because the formalism of physics assumes that step. Hamiltonian mechanics works with complete points in phase space, where each point gives the position and momentum of every particle. Quantum mechanics works with complete state vectors. The specification is taken to be exhaustive by construction. Once the specification is taken to be exhaustive, lawful reversal and faithful reversal collapse into one. The Incommensuration Theorem shows that the exhaustiveness is an idealization. The exhaustiveness is a continuity assumption that cannot be perfected at the same time as the symmetry of the laws. So the formalism assumes what the theorem says cannot be achieved. The assumption is a limit on what the formalism, as a tool, can be taken to say about the real, and the assumption is not a defect of the formalism as a tool.

In 1876 the physicist Josef Loschmidt raised the reversibility objection, which is an early sign of the tension between the symmetry of the laws and the specification of the state. Loschmidt's objection runs as follows. If the laws of mechanics are reversible, then for every trajectory along which entropy rises there is a trajectory, obtained by reversing every velocity, along which entropy falls. The physicist Ludwig Boltzmann replied that the reversed condition is overwhelmingly improbable. In that reply Boltzmann conceded, without saying so, that the constraint that matters is the specification of the state (all velocities exactly reversed), and not the symmetry of the laws of mechanics. The Incommensuration Theorem shows that the constraint Boltzmann conceded is structural: the specification of the state cannot be perfected, because perfecting the specification alongside the symmetry of the laws is the forbidden conjunction. The philosopher of science John Earman has argued that two questions are habitually run together in the physics literature: what time-reversal invariance is, and what time-reversal invariance implies for the direction of time. I distinguish the symmetry of laws from the faithfulness of processes. My distinction is the same clarification as Earman's, carried down to the structural level: the level of the structure of comparison.

IV. Why This Arrow Is Non-Entropic

The entropic arrow is a statistical result about macroscopic systems, which are systems of very many parts, and the entropic arrow requires thermodynamics, the distinction between microstate and macrostate, very many particles, and the Past Hypothesis. A microstate is the exact condition of every particle in a system. A macrostate is the description of the system by large-scale quantities, such as temperature and pressure.

The structural arrow requires none of those four things: thermodynamics, the distinction between microstate and macrostate, very many particles, or the Past Hypothesis. The structural arrow follows from the intrinsics of comparison alone. The structural arrow does not depend on the number of particles, on the concept of entropy, or on the initial condition of the universe. Nor does the structural arrow depend on the coarse-graining that defines a macrostate, the grouping of many microstates under one description. The structural arrow applies to any system in which comparison occurs, and by the Root Tautology of the metaphysics, a system in which comparison occurs is a system in which interaction occurs. The Root Tautology is the recognition, set out in the Introduction, that interaction, comparison and relation are one act named three ways. An interaction is a comparison. A comparison has the structure that the Incommensuration Theorem constrains. The structural arrow is therefore already present before anyone calculates an entropy. The structural arrow is present in any single interaction, and not only in ensembles.

Because the structural arrow is present in every single interaction, I say that the structural arrow is more fundamental than the entropic arrow. The structural arrow is a precondition for thermodynamics, and not something taken from thermodynamics, because every thermodynamic process is built from interactions, and every interaction already has the asymmetry that the Incommensuration Theorem requires.

On the Relationship Between the Two Arrows

The structural arrow underlies the entropic arrow, and does not replace the entropic arrow. The two arrows are joined in every act of recording: a record is itself an irreversible change, and making a record raises the entropy of the instrument that holds the record (*Measurement*). The two arrows are different things that point the same way, and each act of recording is a case of both. The entropic arrow is a mesoscopic consequence, a consequence at the scale of observers and their instruments: the entropic arrow describes how the structural asymmetry shows itself in systems of many parts, where statistical reasoning applies. The structural arrow is the ground: the reason that any process has a direction at all. The two arrows are consistent. The structural arrow is an asymmetry that every process must have. The entropic arrow is that same asymmetry, amplified at the scale of eggs and engines. On the reading in this sidebar, the Past Hypothesis is a statement about initial conditions that fixes how the structural arrow is expressed in the particular history of this particular universe, and is not the source of the arrow. My argument does not say why the initial condition of the universe was what it was. My argument says only that the direction of time does not depend on that initial condition.

What kind of asymmetry is the structural arrow? The structural arrow is the fact that reversal cannot be faithful: the past is not recoverable from the future by running the laws backward, because the state from which the laws would run is never completely given. The structural arrow is not an increase of some quantity that always goes up and never down. The direction of time is the direction in which the residue, the unspecified remainder, is left behind rather than picked up. A process that runs forward leaves the residue behind, and the laws run backward do not pick the residue up again. The unspecified remainder is the same incompressible residue that shows itself as hard randomness and as the irreducibility of the first-person, in the language of my companion discussion in *Accessing the Real*. Hard randomness is randomness determined in no way whatever. I bind hard randomness, the irreducibility of the first-person

and the arrow of time together as a single triple in *Accessing the Real*. I do not restate that binding in this essay, but the arrow of time is the face that the triple shows in time.

V. The Anchor in Conway and Kochen

The argument of this essay, so far, is metaphysical. I would be reassured to find a result in the mathematics of physics itself that agrees with the argument. The theorem of Conway and Kochen is a result in the mathematics of physics that agrees with the argument, and I tie the argument to the theorem as to an anchor. I want to state carefully both what the theorem gives the argument and what the theorem does not give.

The mathematicians John Conway and Simon Kochen published the Strong Free Will Theorem in 2006, and they refined the theorem in 2009. The theorem concerns experimenters who choose which measurements to perform. The theorem states that if the experimenters' choices are not determined by prior information, then the responses of the particles measured are likewise not determined by prior information. The conclusion is conditional: the theorem shows that freedom, if freedom is present anywhere in the experimental arrangement, cannot be confined to the experimenters. In the theorem, freedom means not being determined by prior information. The theorem does not show that experimenters are free. Either the whole arrangement is determined, or indeterminacy is real at the particle as indeterminacy is real at the experimenter. The middle ground is impossible under the theorem: free choice by the experimenters above, with a fixed response by the particles below.

The argument that follows is called the Epistemic Sandwich. The argument works across three layers of physical description, and each layer corresponds to a different scale of reality. The layers are distinct, inseparable, and non-interchangeable. The three scales have the natures of the immanent (mesoscopic), the omniscient (macroscopic), and the transcendent (microscopic). Layer 1 is the mesoscopic scale, the scale of observers and

their instruments. (In this book "mesoscopic" names the observer's own scale, not, as in condensed-matter physics, the scale between atoms and bulk matter.) Newtonian mechanics, electromagnetism, and thermodynamics describe the mesoscopic layer, in generally epistemic terms (terms of knowing), and the key concepts at the mesoscopic layer are causality, change, and choice (omniscient, immanent, and transcendent respectively). Layer 2 is the macroscopic scale, which the theory of General Relativity describes in generally cosmological terms, and the key concepts at the macroscopic layer are the meaningless and the meaningful, with pattern as the mediating term between the meaningless and the meaningful. Layer 3 is the microscopic scale, which the theory of Quantum Mechanics describes in generally ontological terms (terms of being), and the key concepts at the microscopic layer are determinism, relation, and pure randomness. The Incommensuration Theorem forbids two idealizations: determinism (symmetry and continuity both perfected) and pure randomness (asymmetry and discontinuity both perfected). What is real at the microscopic layer lies between determinism and pure randomness.

I build my argument on the theorem of Conway and Kochen, and my argument is conditional in the same way as their theorem. At the mesoscopic layer, the scale of laboratories and instruments, knowledge is bound to the entropic arrow. An observer needs records to measure, to record, or to distinguish an ordered state from a disordered one. Records require an arrow. An epistemic discrimination is an act of telling one state from another as a way of knowing, and every epistemic discrimination at all requires the entropic arrow at the mesoscopic scale. Our knowledge of the other two layers is all mediated through mesoscopic epistemology, the knowing done at the mesoscopic layer: our knowledge of the macroscopic layer, which general relativity describes, and our knowledge of the microscopic layer, which quantum mechanics describes. Mesoscopic epistemology is the only channel connecting the mathematics to the real.

I now apply the theorem of Conway and Kochen to the three layers. Suppose experimenters at the mesoscopic layer make choices that are not fixed in advance, which is what it means for their measurements to be

measurements rather than replays. Then, by the theorem, the responses at the microscopic layer are not determined by prior information either. Indeterminacy at the microscopic layer is a state that is not fully specified, which is to say a state whose reversal cannot be faithful. A state whose reversal cannot be faithful is a non-entropic asymmetry at the quantum scale, present in single events, prior to any ensemble. And any non-entropic asymmetry at the microscopic layer becomes the orienting basis for the entropic asymmetry at the layers above the microscopic layer: the microscopic asymmetry gives the entropic asymmetry its direction.

Because the Epistemic Sandwich is conditional on the experimenters' choices, the conclusion has the form of a choice. Either a non-entropic arrow is real at all three layers, or the entropic arrow on which all knowledge depends is itself absent, and we know nothing at all. The strength of the conclusion is in its conditional structure, and I do not want to overstate that strength. The Epistemic Sandwich shows that denying the arrow requires denying the epistemology on which the denial would have to be made, and so the Epistemic Sandwich does not assert the arrow of time dogmatically. The choice is between knowledge and the absence of knowledge, and not between two theories of physics.

Two points limit the scope of the anchor in Conway and Kochen. First, the theorem of Conway and Kochen is a theorem about determination, and not about temporal direction. I take the step from indeterminate response to non-faithful reversal myself: the step is my reading, and not the result of Conway and Kochen. The step is sound if the bridge between lawfulness and faithfulness, which I argue in Section III, is sound, and the step fails if the bridge fails. Second, the whole anchor is conditional on the antecedent of the theorem: that the experimenters' choices are not determined by prior information. I do not refute, in this section, someone who holds that experimenters' choices are fixed in advance. Superdeterminism is the view that the experimenters' choices were fixed in advance together with what the particles do, and I address superdeterminism on other grounds in the essay on the structural impossibility of superdeterminism, earlier in this volume.

VI. Time as Process, and Not Only as Dimension

On the block universe view, past, present, and future are equally real, time is a static dimension rather than a directed process, and the felt direction of time is a feature of us and not of the world. The block universe view fits determinism, the view that the state of the world at one time fixes the state of the world at every later time. If the future is uniquely fixed by the past, then the future exists in the same sense the past does, and the only thing that moves is our attention, along a line that is already fully drawn.

Time is a triple: geometric time, event time and evolution time are distinct, inseparable and non-interchangeable (*Measurement*). Geometric time is the dimension and exists, while event time is the process and is real. Those who hold the block universe view take geometric time for the whole, and leave out event time.

A separate and older account is about subjective time, the felt length of an interval. The philosopher Paul Janet put forward a proportional theory of subjective time in 1877. Janet's theory states that the apparent length of an interval is inversely proportional to the length of life already lived: an interval is felt as the fraction it makes of the life lived so far. Equal intervals of subjective time then correspond to intervals of objective time that grow in geometric proportion, so that subjective time grows as the logarithm of age. Janet's theory is an explanation of the common observation that time appears to accelerate with age: each year feels shorter than the year before because each year is a smaller fraction of the time already experienced. Janet's theory is a claim of psychology, and not a result of the framework.

I argue in the essay on determinism and causality, earlier in this volume, that determinism is precluded. Determinism is the conjunction of perfected symmetry with perfected continuity. In this essay I argue that perfect time-reversal is precluded by the same conjunction. The two res-

ults are two separate grounds against the block universe view. If determinism is precluded, the future does not exist in the sense the past does. There is a genuine residual, an openness that is not merely our ignorance. If faithful reversal is precluded, the two temporal directions are not equivalent. There is a structural distinction between forward and backward that is not a convention.

Because the future is open and the two directions of time are not equivalent, I place time among the immanent and not among the omniscient. The omniscient is the domain of the structural, the shareable, the repeatable, the same in every context. A dimension is an omniscient notion: a line along which every point has the same standing as every other. Change is immanent: change happens here, now, in the interaction, and change is not the same from both ends. Time is the metric of change, and the arrow is what change looks like when change is compared with itself. Price asks us, with his view from nowhen, to take the omniscient stance on what is an immanent matter. The omniscient stance is available as an abstraction. The omniscient stance is not available as a place from which comparison can actually be made, because comparison is made only in the present, and the present is the site of the interaction itself, and not one point on a line.

The Introduction sets out the three axioms of the metaphysics, and the axioms already have the direction of time in their own form. Axiom II reads as follows, in the words of aphorism 1.3-1 of *An Immanent Metaphysics*. A class of the transcendent will precede an instance of the immanent. A class of the immanent will precede an instance of the omniscient. A class of the omniscient will precede an instance of the transcendent. The cycle runs from the omniscient to the transcendent, to the immanent, and back to the omniscient. The cycle is a cycle of precedence, and not of equivalence. Axiom III reads as follows. The (classes/instances) of the immanent, omniscient, and transcendent are distinct, inseparable, and non-interchangeable. Non-interchangeability is asymmetry at the root, in the axioms themselves. Precedence is order. 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 (*Incommensuration*). The identity of the arrow with that precedence is a structural identity, and the identity shows in the simplest fact about any record: every record follows the act it records (*Comparison*). So this essay has two routes to one arrow: the preclusion of faithful reversal, and the direction of the cycle.

> **Maudlin's Primitivism**
>
> The philosopher Tim Maudlin has argued, in his book *The Metaphysics Within Physics*, that the passage of time is primitive. On Maudlin's view, the passage of time is a fundamental feature of the world, which physics should accommodate rather than explain away, and is not reducible to entropy or to cosmology. I agree with Maudlin's conclusion and differ from him on whether the passage of time is primitive. Maudlin says that the arrow cannot be grounded in anything more basic, while I say that the arrow is grounded in the intrinsics of comparison, and is therefore structural, and not primitive. The arrow is what it means for anything to interact with anything else, and not a brute fact. The difference between Maudlin's view and mine is not small. A brute fact could have been otherwise. A structural requirement could not.

VII. Consistency with Physical Law

My claim that perfect time-reversal is precluded may seem to conflict with the observation that the fundamental laws are time-reversal symmetric. The claim and the observation do not conflict, because of the qualifier in the Incommensuration Theorem. Within any finite domain, symmetry and continuity co-occur to finite degree. The laws exhibit time-reversal symmetry to an extraordinary degree, and my argument does not say otherwise. My argument says that the symmetry cannot be perfect. There is a residual asymmetry: small, difficult to measure, but structurally required.

The residual asymmetry is consistent with known physics, and I read the known physics as an instance of the residual asymmetry. The weak interaction violates CP symmetry (Christenson, Cronin, Fitch, and Turlay, 1964). The weak interaction is the force behind some kinds of radioactive decay. CP symmetry is symmetry under the exchange of particles for antiparticles combined with a mirror reflection, and T symmetry is symmetry under time reversal. By the CPT theorem, CP violation entails T violation. So the accepted description of particle physics already contains an empirically confirmed time-reversal asymmetry, and the CPLEAR and BaBar collaborations have since reported direct observation of T violation as well (CPLEAR, 1998; BaBar, 2012). On the structural reading, the observed T violation is an instance of the kind of asymmetry that I argue must exist. The observed T violation is a place where the impossibility of perfecting temporal symmetry has shown up in what instruments measure, and not a contingent feature of one gauge group, the symmetry group of one particular force.

I want to be exact about the strength of the structural reading: I argue that some asymmetry must exist. The argument does not say how large the asymmetry is, in which interaction it occurs, or through what mechanism. The argument does not predict the observed violation, and I find the observed violation consistent with a structural requirement that would hold whether or not this particular violation had been found. The philosopher Craig Callender has examined whether time is "handed" in the quantum world, that is, whether the quantum world distinguishes one direction of time from the other. Callender concludes that the evidence is more complicated than the CPT theorem alone suggests, and I take Callender's conclusion seriously. The structural argument does not depend on the gauge-theoretic mechanism. So the finer points of the mechanism do not bear on the structural argument.

On CPT and the Structural Arrow

The CPT theorem states that the combined operation of charge conjugation, parity inversion, and time reversal is an exact symmetry of any local quantum field theory. The CPT theorem does not contradict my argument. Under my argument, time-reversal symmetry cannot be perfect when time reversal is taken on its own, apart from every other operation, but my argument says nothing against a compound symmetry that mixes temporal reversal with other discrete inversions. The argument is consistent with the observed pattern, in which CPT symmetry is preserved and T symmetry is violated. The temporal direction cannot be made symmetric by itself. The temporal direction can still take part in a compound where the asymmetry of the temporal direction is compensated by other inversions. I state the agreement as consistency, and not as prediction. The exactness of CPT is exactness within a formalism, and that formalism assumes the continuous specification of state that I discuss in Section III. What is exact in the model is not thereby perfected in the real. The limit is the same limit as in Section III, met from the other side. In Section III the limit was on the complete state that the formalism assumes, and in the case of CPT the limit is on the exact symmetry that the formalism states.

The structural arrow has one further consequence, which concerns the limits of the domain of comparison. I treat three limits of the domain of comparison in the essay on the three horizons, later in this volume. The three limits are the macroscopic boundary set by c, the speed of light; the microscopic boundary marked by Planck's constant; and the mesoscopic present. Each of the three limits is temporal in character: the macroscopic boundary is fixed by how much time has elapsed. The microscopic boundary is fixed by the bound that Planck's constant sets on how finely a comparison can resolve, for the energy brought to the comparison. The mesoscopic present is fixed by the fact that measurement occurs only now. The three limits cannot be interchanged. The non-interchangeability of the three limits is itself an expression of the structural arrow, and I leave the development of that point to the essay on the three horizons.

VIII. Summary

The central claim of this essay is a structural exclusion. A structural exclusion says what physicists will not find, and says so structurally, not numerically. The central claim is that there is a non-entropic arrow of time structurally prior to the thermodynamic one, and that perfect time-reversal is precluded. I identify the structural arrow with the precedence of the second axiom, and that identification is a claim of the metaphysics itself. I read the observed CP and T violation as consistent with the exclusion, and that reading is a reading of a known result. The entropic arrow needs further premises that lie outside the argument of this essay, among them statistical mechanics and the Past Hypothesis.

At the most basic level, the arrow of time is structural, and not entropic.

The Incommensuration Theorem says that symmetry and continuity cannot both be perfected. Perfect time-reversal requires both: the symmetry of the laws under reversal, and the continuity of the state specification that makes faithful reversal possible. Lawful reversal is not faithful reversal. The gap between lawful and faithful reversal is the gap that the theorem names, and the gap cannot be closed. There is therefore an inherent temporal asymmetry that does not depend on entropy, on boundary conditions, or on any particular physical theory.

The structural arrow is more fundamental than the thermodynamic arrow. The structural arrow is a precondition for any process, including the processes from which entropy is calculated. The entropic arrow points the same way as an asymmetry already present at the level of comparison itself, and the entropic arrow and the structural arrow are joined in every act of recording. The weak interaction violates temporal symmetry, and the observed violation is consistent with the structural arrow. I read the violation as an instance of the structural arrow, while claiming nothing about the size of the violation.

Time has a direction because comparison has a structure. The structure of comparison is the incommensuration of symmetry with continuity, and that structure means that no process, at any scale, is perfectly reversible. The arrow of time needs only the fact that something compares to something else, and does not need entropy.

KEY CONCEPTS IN THIS ESSAY

- **Structural arrow of time**: an inherent temporal asymmetry required by the Incommensuration Theorem, independent of entropy or boundary conditions.
- **Entropic arrow of time**: the thermodynamic arrow, the direction of increasing entropy; dependent on statistical mechanics and the Past Hypothesis.
- **Time-reversal symmetry**: sameness of the laws under replacement of t with minus t; an instance of symmetry as defined from the intrinsics; incapable of perfection.
- **Lawful reversal and faithful reversal**: symmetric laws guarantee that the reverse of a process is lawful; symmetric laws do not guarantee that the reverse retraces the original; faithful reversal requires a continuously specified state.
- **Incommensuration Theorem**: when any two of the four compounds are applied absolutely and together, symmetry with continuity and asymmetry with discontinuity are forbidden; the qualifier is part of the theorem.
- **Past Hypothesis**: the assumption that the universe began in a low-entropy state; on this reading, not the source of the arrow but a condition on how the structural arrow is expressed in this universe.
- **The Conway and Kochen theorem**: if experimenters' choices are not determined by prior information, neither are the particles' responses; used here conditionally, as an anchor for a non-entropic asymmetry at the microscopic scale.

- **Block universe**: the view that past, present, and future are equally real; undercut by the preclusion of determinism and of faithful reversal.
- **Time as immanent**: time as the metric of change; change is immanent; the arrow is what change looks like when change is compared with itself.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms), 1.85-4 (causality, change, choice).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The companion discussion of the binding triple of hard randomness, the arrow of time, and subjectivity.

Albert, David Z. *Time and Chance.* Cambridge, MA: Harvard University Press, 2000.

Callender, Craig. "Is Time 'Handed' in a Quantum World?" *Proceedings of the Aristotelian Society* 100 (2000): 247–269.

Callender, Craig. "Thermodynamic Asymmetry in Time." In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Fall 2021.

Conway, John, and Simon Kochen. "The Free Will Theorem." *Foundations of Physics* 36, no. 10 (2006): 1441–1473.

Conway, John H., and Simon Kochen. "The Strong Free Will Theorem." *Notices of the American Mathematical Society* 56, no. 2 (2009): 226–232.

Earman, John. "What Time Reversal Invariance Is and Why It Matters." *International Studies in the Philosophy of Science* 16, no. 3 (2002): 245–264.

Loschmidt, Josef. "Über den Zustand des Wärmegleichgewichtes eines Systems von Körpern mit Rücksicht auf die Schwerkraft." *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Wien, Mathematisch-Naturwissenschaftliche Classe* 73 (1876): 128–142.

Maudlin, Tim. *The Metaphysics Within Physics.* Oxford: Oxford University Press, 2007.

Price, Huw. *Time's Arrow and Archimedes' Point.* Oxford: Oxford University Press, 1996.

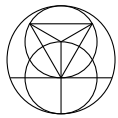
Zeh, H. Dieter. *The Physical Basis of the Direction of Time.* 5th ed. Berlin: Springer, 2007.

Christenson, J. H., J. W. Cronin, V. L. Fitch, and R. Turlay. "Evidence for the 2π Decay of the K_2^0 Meson." *Physical Review Letters* 13, no. 4 (1964): 138–140.

Angelopoulos, A., et al. (CPLEAR Collaboration). "First Direct Observation of Time-Reversal Non-Invariance in the Neutral-Kaon System." *Physics Letters B* 444 (1998): 43–51.

Lees, J. P., et al. (BaBar Collaboration). "Observation of Time-Reversal Violation in the B^0 Meson System." *Physical Review Letters* 109 (2012): 211801.

Janet, Paul. "Une illusion d'optique interne." *Revue philosophique de la France et de l'étranger* 3 (1877): 497–502.



Essay 12

Cross-Modal Reach: Why General Relativity and Quantum Mechanics Cannot Be Unified

On the Two Survivors of the Theorem
and the One Conjunction They Cannot Share

ABSTRACT

Physics has two great theories, and each of the two theories is built on one of the two types of law, the law of symmetry and the law of continuity. General Relativity is built on continuity, the tool proper to the transcendent. General Relativity is applied to the macroscopic, which is the omniscient domain. Quantum Mechanics is built on symmetry, the tool proper to the omniscient. Quantum Mechanics is applied to the microscopic, which is the transcendent domain. So the tool of each theory comes from one modality, and the domain of the theory belongs to the other modality. The tool reaches across the modal divide. In this essay I argue that the reach across is required. A tool applied to a domain of its own modal character says nothing that the domain did not already say, because self-application is semantically empty: a concept applied to itself adds no information. I then read each theory as one of the two surviving conjunctions of the Incommensuration Theorem. General Relativity is continuity with asymmetry, and Quantum Mechanics is symmetry with discontinuity. A single theory whose findings perfected both survivors would perfect symmetry and continuity together, in what is found by one comparison. The Incommensuration Theorem forbids exactly that conjunction. So I read the persistent failure to unify the two theories as a

structural exclusion, and not as a technical difficulty. I read string theory and loop quantum gravity as trade-offs that each program makes on the arena itself, the arena of space and time, and each of the two trade-offs is of a kind the theorem excludes. I set out the reading of gravity as context rather than content, by routes that do not depend on the grid of the six measures. I say that gravitation has no quanta, and I say in what sense a description of the small waves of gravitation has quanta. I connect the argument to the problem of time and to the complementarity of Niels Bohr, and I close by saying what kind of claim the exclusion is, and what the exclusion does not exclude.

Note on framework. This essay depends on the Introduction to this volume for five things: the six intrinsics, the four secondary compounds, the Incommensuration Theorem, the three axioms, and the modal alignment. This essay also depends on two essays in Part I, the essay on the two types of law and the essay on the six measures. This essay is the companion to the essay on the wave and the particle in Part II, in which I found the two survivors of the Incommensuration Theorem inside Quantum Mechanics alone. I develop points of this essay further in two later places: the essay on three kinds of acceleration, which follows this essay, and the essays on the three horizons in Part IV. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Problem as Physics Has It

For a century physics has had two fundamental theories, where physicists want one. General Relativity has been complete in its essentials since 1915. General Relativity describes gravitation as the geometry of spacetime: a smooth continuum of events, whose curvature is fixed by the distribution of mass and energy, and whose curvature in turn fixes how mass and energy move. Quantum Mechanics was complete in its essentials a

decade later. Quantum Mechanics describes matter and the other forces as states in a space of possibilities, and the states evolve by rules of invariance and, when the states are measured, yield discrete outcomes with definite probabilities. Each theory has been confirmed to a precision that leaves no serious doubt that the theory is correct within its range, and each theory predicts phenomena that the other theory cannot address. Yet the ranges of the two theories are forced to overlap in three places, and there the two theories contradict one another. The first place is the Planck scale, the extremely small scale at which the effects of gravity and of quantum theory are both strong. The second place is the singularities of black holes, and the third place is the earliest moments of the cosmos.

The standard response of physicists has been to seek a unification: a single theory of which both theories would be limiting cases, special cases to which the single theory reduces in some range. Physicists call the sought single theory a theory of quantum gravity. The proposed theories make a long list: string theory, loop quantum gravity, causal set theory, twistor theory, asymptotic safety and emergent gravity. The literature of each proposal is deep. The mathematical physicist Roger Penrose has written, in *The Road to Reality*, that the interface between the two theories will require a conceptual revolution. In Penrose's judgment the revolution will be comparable to the revolutions that produced the two theories. Penrose also holds that neither theory can be regarded as more fundamental than the other. The physicist Chris Isham has set out with great care what any theory of quantum gravity would have to do to be a theory at all. The physicists Carlo Rovelli and Lee Smolin are each committed to a program of quantum gravity, and both have acknowledged in writing how far the programs are from the unification that the researchers set out to reach.

Physicists usually describe the situation by saying that the unification is hard, but I describe the situation differently. In this essay I argue that the unification, in the strong sense that Section VI states, is not possible. The reason is a fact about comparison, and not a fact about physics: physics is measurement, and every measurement is an act of comparison, so physics cannot escape a fact about comparison. I want to make the argu-

ment carefully, for two reasons. The claim of impossibility is among the strongest claims this book makes about physics. And whoever makes a claim of impossibility owes the reader a precise statement of what exactly is called impossible.

II. The Two Tools and the Three Domains

I set out the structure that the argument of this essay uses in the Introduction to this volume, and in this essay I recall the structure only as far as the argument needs. Every comparison involves six intrinsics: sameness and difference, content and context, and the subjective and the objective, where a content is what is being compared and a context is the frame of the comparison. When sameness and difference are applied to content and context, sameness and difference yield four secondary compounds. Continuity is sameness of content within sameness of context. Discontinuity is difference of content within sameness of context. Symmetry is sameness of content across difference of context. Asymmetry is difference of content across difference of context.

The Incommensuration Theorem says that when any two of the four compounds are applied absolutely and together, two conjunctions are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two conjunctions survive as valid absolute conjunctions: continuity with asymmetry, and symmetry with discontinuity. I call the two surviving conjunctions the two survivors. The qualifier "absolutely and together" is part of the theorem. Within any finite domain, symmetry and continuity occur together to a finite degree, but symmetry and continuity cannot both be perfected at once.

I argued in the essay on the two types of law that all law is either symmetry law or continuity law. The modal alignment of this book is fixed: symmetry is omniscient, continuity is transcendent, and interaction is immanent. The omniscient, the transcendent and the immanent are the three modalities of the Introduction: the omniscient is the mode of structure,

the transcendent is the mode of the generative, and the immanent is the mode of process. Symmetry is the omniscient's tool, because sameness of content across difference of context is what the structural, the repeatable, the shareable is: what any observer, anywhere, will find again. Continuity is the transcendent's tool, because sameness of content within sameness of context is what the connected, the whole, the unbroken is: the field of possibility from which a thing does not depart while the thing remains itself. Interaction is immanent, because interaction is the here and now in which content and context come together at all.

There is a second alignment, an alignment of domains rather than of tools, and the argument of this essay depends on the second alignment. The macroscopic is the omniscient domain. The macroscopic is the layout of the whole, the pattern seen from outside: things existing in their structural relations, and the cosmos as a shareable third-person fact. The microscopic is the transcendent domain. The microscopic is the region of the not-yet-manifest, of potentiality and probability and possibility, and the region of the singular event that is only itself and exceeds any single structural description. The mesoscopic lies between the macroscopic and the microscopic. The mesoscopic is the human scale, the scale at which measurement is performed, and the immanent domain, the domain of interaction. I develop the three scales as boundaries in the essay on the three horizons, in Part IV, but in this essay I need only the modal character of the three scales.

III. The Cross-Modal Observation

Now consider how General Relativity and Quantum Mechanics are actually built.

General Relativity is built on continuity. The foundational object of General Relativity is a smooth, differentiable continuum of events. The continuum is a geometry that admits no gaps, no jumps and no discrete elements. The field equations of General Relativity are differential equa-

tions, and the field equations require smoothness for their solutions to exist. The principle of equivalence is the founding physical idea of General Relativity, and the principle is a statement of continuity. Inertial motion is motion on which no force acts. The principle of equivalence says that at any point free fall and inertial motion are one and the same. So the geometry joins the local physics with no boundary between the geometry and the local physics. A theory's findings are the results of the measurements made under the theory. In the findings of General Relativity, continuity is constitutive. Continuity is part of what makes General Relativity the theory it is. General Relativity is also invariant under every smooth change of coordinates. The invariance is a symmetry of the formalism of General Relativity, the mathematics in which the theory is written. So the invariance is a symmetry of the description, and not a finding. Continuity is the transcendent's tool.

Yet General Relativity describes the macroscopic. General Relativity describes the large-scale form of the universe: the overall shape of spacetime, the motions of planets and galaxies, the curvature of the cosmic geometry, the horizons of black holes, and the expansion of the whole. The horizon of a black hole is the boundary from inside which nothing comes back out. The macroscopic is the omniscient domain.

Quantum Mechanics is built on symmetry. The findings of Quantum Mechanics are invariant. The findings are the exchange symmetry of identical particles, the discrete quantum numbers by which states are classified, and the charges that fix which interactions there are. Each force is defined by a gauge symmetry. Where the gauge symmetry of a force is exact, the charges of the force are conserved without exception. Conservation follows from invariance, by way of Noether's theorem, which the mathematician Emmy Noether proved, and conservation is the structural backbone of every calculation in Quantum Mechanics: every calculation depends on the conserved quantities. The unitary group is the continuous group of transformations that governs how a quantum state evolves, and the unitary group acts in the formalism of Quantum Mechanics, on a con-

tinuous space of states. In the findings of Quantum Mechanics, symmetry is constitutive. Symmetry is part of what makes Quantum Mechanics the theory it is. Symmetry is the omniscient's tool.

Yet Quantum Mechanics describes the microscopic. Quantum Mechanics describes the evolving potentiality of what is not yet manifest: the superposition of possible states, the amplitudes that weight the outcomes, the single decay, the single click, the event that is only itself. The microscopic is the transcendent domain.

So in each theory the constructive principle, the principle on which the theory is built, belongs to the opposite modality from the domain that the theory describes. General Relativity uses a transcendent tool to describe an omniscient domain, and Quantum Mechanics uses an omniscient tool to describe a transcendent domain. I call the use of a tool of one modality to describe a domain of the other modality the cross-modal reach. A theory's tool is the character, continuity or symmetry, that the theory perfects in its findings. The reach of each theory is dense but never exhaustive in the domain of the other modality: the theory applies as closely as one likes, everywhere in the domain, and never to the whole of the domain (*Measurement*, Chapter 8).

Naively, one would have expected the structural tool to describe the structural domain, and the tool of potentiality to describe the domain of potentiality. Physics developed the other way round, in both cases. Different people built the two theories for different reasons, without any thought of modality at all. The pattern of the two crossings is clean enough that I do not think the pattern is an accident. Section IV gives the reason for the pattern.

IV. Why the Reach Is Required

In the Introduction I give the argument for the Incommensuration Theorem. In that argument I dispose of the ten pairings of the four compounds by three considerations. The ten pairings are the ways of taking

two of the four compounds, a compound with itself or with another compound. The first consideration is that self-application is semantically empty. Symmetry of symmetry is symmetry. Continuity of continuity is continuity. Applying a concept to itself adds no information, because the duplicate says nothing that the single term did not say. A tool of one modal character, applied to a domain of the same modal character, is self-application at the scale of a theory.

Apply the emptiness of self-application to physical theory. Suppose a theory used symmetry to describe a domain whose character is symmetry. The theory would be a structural description of structure, a map of a map, a pattern of a pattern. The theory would be tautological. The theory would say of the domain only what the domain already is, because the tool and the domain would be one concept applied twice. The Incommensuration Theorem identifies a concept applied twice as empty. Suppose instead a theory used continuity to describe a domain whose character is continuity. The theory would be connectedness describing connectedness, participation in participation, process of process. Continuity applied to continuity is self-application too, and the theory says nothing.

A theory is informative when the theory says something about its domain beyond what the domain already is. For a theory to be informative, the constructive principle of the theory must come from a different modality than the domain that the theory describes. The tool must reach across the modal divide, the divide between the omniscient and the transcendent. The requirement that the tool reach across is the condition under which a description can be a description at all. The requirement is neither a preference nor a historical habit.

There is a second way to see that the reach is required, from the axioms rather than from the theorem. Axiom I says that the omniscient and the transcendent are in conjugate relationship to one another. When two conditions hold of two things, the two things are conjugate (*Incommensuration*, Chapter 10). First, each of the two things can be perfected only at the expense of the other. Second, neither of the two things is prior to the other in definitional basis. If a theory perfected both members of a conjug-

ate pair in its findings, the theory would perfect two conjugates at once. Perfecting two conjugates at once is the exclusion that Section VI states for symmetry and continuity. In this paragraph the exclusion is stated in the names of the modal roles, the omniscient and the transcendent. Neither the omniscient nor the transcendent is prior to the other, so each is reached by way of the other: each is described with the tool of the other. To learn the shape of the omniscient, one reaches into the omniscient with the transcendent's instrument, and to learn the shape of the transcendent, one reaches into the transcendent with the omniscient's instrument. Conjugacy, put to work, means reaching into each of two conjugates with the instrument of the other. So General Relativity and Quantum Mechanics are not merely permitted to cross the modal divide. The two theories cross because crossing is how conjugates give an account of one another.

There is a third way to see that the reach is required, from the Incommensuration Theorem itself. Symmetry and continuity cannot be conjoined absolutely, so no single theory can describe both domains by finding both characters perfected. Each theory perfects one of the two characters in its findings, and the domain that the theory describes informatively is the domain whose modality is the modality of the other character (*Incommensuration*, Chapter 8, Section III). In each case the tool and the domain differ in character, for the reason of the first way: if the two characters were the same, the theory would be empty, because self-application is empty.

I want to be clear about whether the cross-modal reach changes the alignment of the two laws. The cross-modal reach leaves the alignment as the alignment was: symmetry is still the omniscient's tool, and continuity is still the transcendent's tool. The two assignments hold at the level of the intrinsics, where I make the assignments. The cross-modal reach shows that a theory's tool need not share the modal character of the theory's domain, and in fact the tool must not share the modal character of the domain, if the theory is to say anything. I count the rule as a subtlety about the alignment, and not as a revision of the alignment: the rule says that a tool must not share the modal character of its domain.

V. The Two Survivors Made Physical

Up to this point my argument has used only two single compounds, symmetry and continuity. The Incommensuration Theorem, however, is about conjunctions, and when the two theories are examined more closely, the two theories are conjunctions too.

General Relativity is continuity with asymmetry. The constructive principle of General Relativity is continuity: the smooth geometry, the unbroken field, and the join of free fall to inertia, with no boundary at the join. And in every solution of the field equations, continuity produces asymmetry: difference of content across difference of context. The curvature breaks the homogeneity of flat space, the sameness of flat space from place to place. So no two regions of a curved geometry are alike. Mass at one place is not mass at another place, and the curved geometry records the difference. The lightcone structure is directed: the lightcones at each event separate the future of the event from the past of the event. Horizons are one-way, and collapse is irreversible. Continuity and asymmetry are present together in every feature of General Relativity, and the continuity generates the asymmetry, by way of the field equations. General Relativity is the first survivor of the Incommensuration Theorem, continuity with asymmetry, made physical in a theory of the world.

Quantum Mechanics is symmetry with discontinuity. The constructive principle of Quantum Mechanics is symmetry: invariance under the unitary group, under exchange, and under the gauge transformations that define the forces. And whenever the theory is brought to bear on the world, symmetry produces discontinuity: difference of content within sameness of context. Energy comes in levels, and a measurement gives one outcome of many. What is found is discrete, whatever account anyone gives of how the outcome comes about. Symmetry and discontinuity are present together in every feature of Quantum Mechanics, and the symmetry generates the discontinuity, by way of quantization. The discrete

spectrum is the shadow of the invariance, as I argued in the essay on the two types of law: the separate values that a quantity can take follow from the invariance of the theory. Quantum Mechanics is the second survivor, symmetry with discontinuity, made physical in a theory of the world.

A physicist will object at this point, and the objection is a good one. General Relativity is full of symmetry. General Relativity is invariant under all smooth changes of coordinates, and the local physics of General Relativity is Lorentz invariant: the local physics is the same for every observer in uniform motion. Quantum Mechanics is full of continuity: the wavefunction evolves smoothly, the space of states is a continuum, and the amplitudes vary without a break. If each theory has both symmetry and continuity, how can either theory be read as one survivor?

On Which Compound Is Perfected

The answer is that a physical theory has two levels: the theory's formalism, which exists, and the theory's findings, which are real. The Incommensuration Theorem constrains which character a theory perfects in its findings. The conjugate character is the character that a theory does not perfect in the findings of the theory. The conjugate character is exact in its own right, and the formalism of the theory carries the conjugate character. General Relativity finds a smooth geometry, perfected without exception. General Relativity is written in a formalism whose symmetry is exact: the symmetry is invariance under every smooth change of coordinates, and the symmetry is a symmetry of the description, not of the world found. The findings of Quantum Mechanics are exact labels, the charges and the quantum numbers, perfected without exception. Quantum Mechanics is written in a formalism whose continuity is exact at the level of the formalism. The continuity is the smooth unitary evolution of amplitudes. Every finding of Quantum Mechanics is one definite outcome, whatever account anyone gives of how the outcome comes about. So each theory perfects one compound in its findings and the other compound in its formalism, at two levels, and the split between the two levels is exactly what the Incommensuration Theorem permits (*Incommensuration*, Chapter 10; *Measurement*, Chapter 8). A continuous symmetry shows the

> split between the two levels in miniature. The symmetry of a continuous symmetry is found, as a conserved quantity, and the continuity of a continuous symmetry is carried in the formalism, as the smooth parameter of the group. For example, a law that is symmetric under rotation has a conserved angular momentum, and the angle of rotation is the smooth parameter of the group of rotations.

I found the same two survivors inside Quantum Mechanics alone, in the essay on the wave and the particle: the wave is continuity with asymmetry, the particle is symmetry with discontinuity, and the measurement that reveals the wave and the particle relates the wave to the particle. The reading of the wave and the particle does not conflict with the reading of the two theories in this essay. The wave aspect is the continuity that Quantum Mechanics carries in its formalism. The particle aspect is the symmetry that Quantum Mechanics perfects in its findings. The physicist Niels Bohr set out complementarity in a paper of 1928. Bohr's complementarity is the recognition that the wave description and the particle description cannot both be given at once, and that each of the two descriptions captures what the other must leave out. I read Bohr's recognition as an instance of the general result, found within one domain: the two survivors, seen from inside one theory. Between the two theories, the complementarity of the two survivors appears again, at the scale of the whole of physics. General Relativity elaborates space and time and leaves out possibility. Quantum Mechanics elaborates possibility and how possibility evolves in time, and leaves out actuality. So General Relativity and Quantum Mechanics are mirror images across the basis of space, time and possibility.

VI. What a Unification Would Have to Be

Physicists usually mean one thing by a unified theory of quantum gravity. In the usual sense, a unified theory of quantum gravity would be a single theory of which General Relativity and Quantum Mechanics are

both limiting cases, and which is more fundamental than either. To recover General Relativity in its limit, the unified theory would need to find a continuous geometry, with continuity perfected in its findings. To recover Quantum Mechanics in its limit, the unified theory would need to find exact invariants, with symmetry perfected in its findings. So the unified theory would need to perfect both compounds at once, in what is found by one and the same comparison.

The two surviving conjunctions are structurally dual: each survivor is defined by the absence of what the other survivor is defined by. Continuity with asymmetry is the conjunction that does not include symmetry, and symmetry with discontinuity is the conjunction that does not include continuity. If one theory found both survivors, perfected, the theory would conjoin symmetry with continuity absolutely, and the Incommensuration Theorem forbids that conjunction. In the Introduction I give the reason for the prohibition in a few lines. If content is the same whether or not the context changes, then the content has no dependence on context. Every comparison requires the distinction between content and context, and when content has no dependence on context, nothing holds the distinction apart.

The claim of this essay is that the persistent failure to unify the two theories is a structural exclusion, and not a technical failure. The failure to unify is not a failure of mathematical ingenuity, of physical insight, or of experimental guidance. I find the same structural exclusion in the essay on determinism, in the demand for perfect causal law, and in the essay on Bell's theorem, in the demand for lawfulness and locality together. In each case the structural exclusion is an instance of the Incommensuration Theorem, and the failure to unify the two theories is the instance at the largest scale on which physics operates.

I need to say exactly what kind of claim the exclusion is: the exclusion is an impossibility claim, not a difficulty claim. A difficulty claim says the problem is hard and might be solved by a cleverer person, while an impossibility claim says that what is asked for is not a coherent thing to ask for. In the sense that the logician Kurt Gödel's theorems address, nobody

can coherently ask for a formal system that is both complete and consistent either. Each kind of claim needs a different response: to a difficulty, one responds with more effort. To an impossibility, one responds by asking what the coherent version of the request is, and by pursuing the coherent version instead.

I need to say, just as exactly, what the exclusion does not exclude. The exclusion does not rule out a consistent theory that agrees with General Relativity at large scales and with quantum field theory at small scales, provided the theory does not find both survivors perfected in one comparison. Quantum field theory is the form of quantum theory that physicists use for the forces and the particles. Nor does the exclusion rule out gravity treated at low energies as an effective field theory, with quanta of the description of the small waves of gravity. An effective field theory is a description that holds only below some energy. The arena is space and time, the background of every comparison. A small wave of the arena can be described as if the wave were content, and the description then has quanta. The quanta are quanta of the description and never quanta of the arena, as phonons are quanta of the description of sound in a solid. A phonon is the smallest packet of vibration in a crystal. The phonon is only the nearest sense in which a quantum of the description of the arena can be made intelligible. A crystal is a held structure: the atoms of a crystal are held in place by the forces between the atoms. The arena is not a held structure, so even the sense of the phonon does not make a quantum of the description a quantum of the arena. The exclusion rules out one theory whose findings perfect continuity and symmetry together.

The coherent version of the request for unification is available in the metaphysics of this book. Axiom I says that the immanent is more fundamental than the omniscient and/or the transcendent. Axiom I also says that the omniscient and the transcendent are in conjugate relationship to one another. The two theories are the omniscient and the transcendent reaching across into one another: each theory applies the tool of one of the two conjugate modalities to the domain of the other. The immanent relates the two theories. The immanent is the interaction, the measure-

ment, in which the geometry and the quantum state are both brought to bear on a single event, and no third formalism standing above both theories relates the two theories. I state the same point in the companion essay on the six measures, in the terms of the grid of the six measures. The grid has a column for each modality. Mass in space is the omniscient column, force in time is the immanent column, and probability in possibility is the transcendent column. The two theories share the immanent column, force in time, but the two theories do not share the immanent column in the same way: General Relativity treats force in time continuously, and Quantum Mechanics treats force in time discretely. A unification would have to connect the omniscient column to the transcendent column without passing through the immanent column. The first axiom says that every connection between the omniscient and the transcendent passes through the immanent. The connection between the two theories runs through the interaction, and not directly from one theory to the other. So the two theories are already unified, in the only way the two theories can be unified: the two theories are the two conjugate aspects of one domain of comparison, and the two aspects come together in the act of measurement. The unity of two conjugate aspects is a product, not a merger. The sidebar "Conjugation, Not Merger" in Section VIII sets out the sense of the word product: the two aspects stay distinct, and neither can be eliminated in favor of the other. I think the unity of a product is what Penrose's conceptual revolution would have to turn out to be.

Axiom I applies to the three scales of the domain as well. The mesoscopic is more fundamental than the microscopic and/or the macroscopic, because every finding about the microscopic or the macroscopic is made by an interaction at the mesoscopic scale, where every measurement is made. The macroscopic (omniscient) and the microscopic (transcendent) are the conjugate pair.

A further consequence follows from the place of the mesoscopic scale as the ground, in the sense of Axiom I. Both Quantum Mechanics and General Relativity are reached from the mesoscopic scale. Every measurement that tests either theory is made with instruments at the human scale.

In Quantum Mechanics, the wavefunction is defined over the configuration space of classical mechanics. The configuration space is the space of all arrangements of the parts of a system. In General Relativity, the Lorentzian manifold generalizes the geometry of classical space and time. The Lorentzian manifold is the curved spacetime of the theory. The mathematical apparatus of both theories was first developed in the classical context: differential equations, variational principles and symmetry groups. In the terms of Axiom I, the mesoscopic is immanent, and the two boundary theories are related through the mesoscopic: General Relativity, applied to the omniscient macroscopic, and Quantum Mechanics, applied to the transcendent microscopic. Mechanics was found first, at the mesoscopic scale, and the order of discovery fits the place that Axiom I gives the immanent, as the ground: the scale at which comparison is performed is the scale from which all other physics is reached.

The two theories are written together in only one formalism, and the formalism shows the coherent form exactly. The formalism is the spectral geometry of the physicist Ali Chamseddine and the mathematician Alain Connes. In the spectral geometry, the arena and the content are two factors of one product: "the two modes composed side by side". "The conjunction is mediated by scope", and the product is "not a single geometry perfecting both characters". "The Dirac operator of the product acts on each factor in its own character". The Dirac operator is the operator from which the spectral geometry reads off both the geometry and the particles. So the formalism states the thesis of this essay: what relates the two theories is the act. Only one step of the spectral geometry imposes one common measure across the two factors. The step is the trace of the spectral action over the whole product. At that step the spectral geometry sets relations at the cutoff, and the relations depart from the measured weak angle and the measured Higgs mass. The cutoff is the energy scale at which the spectral action is defined. Incommensurable means having no common measure (*Non-Commutative Geometry and the Immanent Meta-*

physics, Chapters 13 and 15). So the spectral geometry departs from measurement at exactly the one step at which the two factors are given a common measure.

VII. Partial Trade-Offs

The Incommensuration Theorem precludes the simultaneous perfection of symmetry and continuity in the findings of a single theory. The theorem does not preclude every approach to quantum gravity, but the theorem predicts that every program of quantum gravity will turn out, when examined, to have made a trade-off between the two survivors. A partial trade-off gives up some symmetry to keep continuity, or some continuity to keep symmetry. When the researchers in a program keep the arena of space and time out of the quantum state, the trade-off is of the kind the theorem permits. When the researchers put the arena itself into the quantum state, the researchers treat the context of physics in the way that belongs to content, and the program then requires one of the two pairings the theorem excludes (*The Unquantized Arena*, Chapter 14, "Four Criteria and Ten Programs"). I can read the programs by the two kinds of trade-off, and the reading is independent of the technical success of the programs. I offer the distinction as a reading, with a caveat: anyone working inside either of the two programs I read next, string theory and loop quantum gravity, may fairly say that the reading is a coarse one.

String theorists keep the symmetric tool whole and let the geometry become secondary. String theory contains the full apparatus of Quantum Mechanics. In string theory the apparatus is extended with further invariances and with dualities, beyond the invariances that Quantum Mechanics had. A duality is an exact equivalence between two descriptions that look different. String theorists concede General Relativity's constitutive continuity, and in string theory the smooth geometry is no longer the primary object. The smooth geometry is a background on which the symmetric structure is defined, or something to be recovered from the sym-

metric structure in a limit. In string theory, gravity itself is treated as content, as one mode among the modes of the string. On this reading, string theorists have sacrificed some of continuity to keep symmetry perfected.

Researchers in loop quantum gravity make the opposite trade. Researchers in loop quantum gravity keep the constitutive geometry of General Relativity: there is no background, the geometry is the primary object, and the relational, whole-first character of General Relativity is preserved. Researchers in loop quantum gravity concede the exact global symmetry of Quantum Mechanics: in loop quantum gravity the invariances of flat space are to be recovered only in a limit, and the recovery has been the recurring difficulty of the program. The geometry is quantized, so areas and volumes come in discrete values. Discrete values of area and volume are the discontinuity that symmetry generates, applied to the context itself. Researchers in loop quantum gravity take the discrete spectra as what a measurement of area or volume would find: a least step of space. So the program contains a forbidden pairing, because context has no least step (*Incommensuration*, Chapter 5; *The Unquantized Arena*, Chapter 14, Section IV). The verdict of the Incommensuration Theorem concerns what a program requires its findings to be. A founding commitment is the operation that the researchers in a program perform on the arena at the first step of the program. The founding commitment fixes what the program requires its findings to be, before any calculation is made. The computations made under the founding commitment succeed or fail by the standards of physics. On this reading, researchers in loop quantum gravity have sacrificed some of symmetry to keep the primacy of continuity.

The other programs can be read in the same way. In causal set theory the continuum is made discrete outright, and researchers in causal set theory seek to recover the continuum statistically. A lattice is a regular grid of points. A lattice and a causal set each have a least step, and from the metaphysics of this book I expect that no least step of space or time will be found. Researchers in asymptotic safety keep the continuum. The researchers ask the symmetric apparatus to behave at short distances in a way the apparatus has not been made to behave elsewhere. The apparatus

is the metric treated as a quantum field. In General Relativity the metric is the quantity that gives distances and durations. So the program of asymptotic safety contains a quantum state of the geometry, past the Planck scale, as the foundation of the arena. The arena has no quantum state of the geometry past the Planck scale, because gravitation has no quanta, and past the Planck scale no description takes over (*The Unquantized Arena*, Chapter 14, Section IV). In each of the programs, the researchers give up something from one survivor to gain something from the other survivor. The sacrifice is the structural signature of the theorem at work, the sign in a program that the Incommensuration Theorem holds, and I expect the sacrifice to be found in every proposal that is ever made. In four programs the sacrifice is made on the arena itself: string theory, loop quantum gravity, causal set theory and asymptotic safety. In each of the four programs the context of physics is treated in the way that belongs to content, and each of the four programs requires one of the two pairings the theorem excludes. So the researchers in each of the four programs ask for a merger that the theorem excludes, and none of the four programs makes a partial trade-off of the kind the theorem permits (*The Unquantized Arena*, Chapter 14, Sections IV and VI).

How to Read a Proposal

I put a single question to any proposed unification: where does the proposal sacrifice symmetry for continuity, or continuity for symmetry? If the answer is nowhere, so that the proposal claims to find both symmetry and continuity perfected, then I expect, from the metaphysics of this book, that the proposal is incomplete or inconsistent in a place that no one has yet examined. If the answer is a definite place, and the proposal keeps the arena of space and time out of the quantum state, the proposal is a partial unification of the kind the theorem permits. Whether a permitted partial unification is a good one is a question of physics, not of metaphysics. In this essay I take no position on the question. If the answer is a

> definite place, and the proposal makes its sacrifice by putting the arena itself into the quantum state, the proposal treats a context as a content, and the proposal requires one of the two pairings the theorem excludes.

VIII. Gravity as Context

I offer one further reading, from the metaphysics of this book, a reading of what gravity is, and the reading bears on what researchers in the unification programs have most often looked for: a particle of gravity.

I arranged the six intrinsics of measurement, the six measures, in a grid, in the companion essay on the six measures: the grid has three modal columns and two rows, content on one side and context on the other. The content row is mass, force and probability, and symmetry law governs the content row. The context row is space, time and possibility, and continuity law governs the context row. Gravity is in no cell of the grid: gravity is the shape of the context row, the curvature of space and time by which mass and force are related to the setting of mass and force. I put the point directly in the essay on the domain boundary: space is the topology of connectivity, and the curvature is the gravitation. On this reading, gravity is context rather than content. Gravity is the form of the domain itself, and not an occupant of the domain, and the form of the domain is the geometry of the paths along which signals and bodies can go.

Physicists have a standard line of argument about a particle of gravity at a black hole. The argument bears directly on the reading of gravity as context. (In this book the word graviton means, at most, a quantum of a description: the description of small waves of a classical geometry. The word never means a quantum of the arena.) If gravity is mediated by graviton particles, how do gravitons escape a black hole to communicate the gravitational field beyond the horizon? The standard response of physicists is that the external field was established before the horizon formed, and that virtual gravitons do not need to travel outward, because virtual gravitons are off-shell. An off-shell particle is free of the relation

between energy and momentum that a real particle obeys. The standard response is mathematically consistent within the perturbative framework, the method of calculating by successive small corrections. But the standard response requires "virtual particles" to differ in kind from real particles, in exactly the way needed to avoid the problem. In the terms of the Immanent Metaphysics, I draw an inference from the standard response: if the gravitational field is not being signaled outward, then the gravitational field is a feature of the geometric context, and not a consequence of particle exchange. The inference agrees with the claim of this section: gravity is context rather than content.

Conjugation, Not Merger

In the Immanent Metaphysics, conjugation is distinct from opposition and from merger. Opposition is additive: if one aspect increases, the other decreases by the same amount, and one of the two aspects can reach zero. Conjugation is multiplicative: neither aspect can reach zero, and neither aspect can be eliminated in favor of the other. Axiom I is written $I = O \times T$, where I, O and T stand for the immanent, the omniscient and the transcendent. In the formula the immanent is read as the conjugate relationship of the omniscient and the transcendent, and not as a multiplication of quantities. At the microscopic limit of a domain, the conjugation appears in the form of strict opposition. At the macroscopic limit, the degree of realness of either aspect is directly proportional to the degree of realness of the other aspect (*Incommensuration; The Theorem and the Three Axioms*, Chapter 8, Section IX). A merger would collapse the distinction between the two terms entirely. General Relativity and Quantum Mechanics are conjugates. The two theories are distinct, because each theory perfects a different conjunction, and inseparable, because every finding has a content and a context. The two theories are non-interchangeable, because neither theory can do the work of the other. The two theories do not oppose each other, and the two theories cannot be merged. The two theories are two descriptions of one domain, and each description captures what the other must leave out.

The principle of equivalence says, from inside physics, what the reading of gravity as context says. Every body, whatever the body is made of, falls in the same way. Falling in the same way is sameness of content across difference of context: symmetry, of the plainest kind. The symmetry of the fall makes gravity belong to all contents alike, rather than to any one content, and a thing that belongs to all contents alike is the setting that all contents share, and not a content. I develop the point from the side of what is felt in the essay that follows this essay, the essay on three kinds of acceleration. A body can undergo three kinds of acceleration, and only the gravitational kind is one that no local push can produce, because gravitational acceleration is the shape of the setting and not an action within the setting.

If gravity is context rather than content, gravity has no particle, because every particle is a kind of content, and gravity then has no label carried in steps, no charge, and no carrier that a shield could stop. A small wave of the arena can be described as if the wave were content, and the description then has quanta. The quanta are quanta of the description and never quanta of the arena, as phonons are quanta of the description of sound in a solid. A phonon is the smallest packet of vibration in a crystal: a quantum of the description of sound, and not a separate thing in the crystal. The phonon is only the nearest sense in which a quantum of the description of the arena can be made intelligible. A crystal is a held structure, and the arena is not a held structure, so even the sense of the phonon does not make a quantum of the description a quantum of the arena. The arena itself stays context, because the arena is the background of every comparison (*Measurement*, Chapter 3). Whoever looks for a particle of gravity at all treats a context as a content. The demand for unification contains the confusion of context with content too, at the level of theories. Physics has its own versions of the thought that gravity is context. The physicist Ted Jacobson reads the field equations of General Relativity as an equation of state. An equation of state is the kind of equation that relates the temperature, pressure and volume of a gas. The physicist Erik

Verlinde reads gravity as entropic: as arising from entropy, the count of the arrangements of a system. I take the readings of Jacobson and Verlinde as evidence that the reading of gravity as context is not foreign to physics.

The reading of gravity as context does not depend on the six-measure grid, and the reading follows by three other routes. First, anything that plays the role of context has four markers: the thing couples to everything, admits no shield, has one mass for coupling and for inertia, and carries no charge in steps. Gravity has all four markers (*Measurement*, Chapter 10). Second, in *Incommensuration* I derive the law of continuity for all that is of context, with the reason that context has no least step, and I identify the arena of space and time as context. Third, in the spectral geometry of the product, gravity comes from the arena factor, and the field space has no spin-two field (*Non-Commutative Geometry and the Immanent Metaphysics*, Chapters 13 and 19). A spin-two field is the kind of field whose quanta would be gravitons.

IX. The Problem of Time, and the Tradition

The physicist Chris Isham identified what is now called the problem of time in quantum gravity, alone and with the philosopher of physics Jeremy Butterfield. In General Relativity, time is geometric. Time is a dimension of the continuum, with no preferred slicing of spacetime into moments and no external clock. In Quantum Mechanics, time is a parameter. Time is the variable against which the state evolves, external to the system and shared by all of the system. Anyone who attempts to quantize the geometry has to decide whether time is geometric or a parameter. Neither answer fits both theories: time as geometric does not fit Quantum Mechanics, and time as a parameter does not fit General Relativity.

The problem of time is the cross-modal reach, applied to time specifically. There are three times to consider: the time of General Relativity, the time of Quantum Mechanics and the time of measurement. General Relativity's time is omniscient: geometric, structural, reversible in its equa-

tions, and the same for every observer who reads the geometry. Quantum Mechanics's time is transcendent: parametric, evolutionary, sweeping through possibilities that have not yet resolved. The moment of measurement is the time of the interaction, and the moment of measurement is immanent: at that moment the times of the two theories come together and disagree. I argued in the essay on the structural arrow of time, earlier in this Part, that the arrow of time is a feature of the immanent, of process, and not a feature of the omniscient alone or of the transcendent alone. The problem of time is what one gets by asking the two conjugate times to be one time, without going through the third time, the time of measurement.

The physicist John Archibald Wheeler began a program under the slogan of the bit that precedes the it: information comes before the physical thing. Wheeler looked for something more fundamental than either spacetime or the quantum state, and so have the researchers who followed Wheeler in the information-theoretic approaches. In this book I begin with the Root Tautology, which says that comparison is interaction is relation. The Root Tautology is a starting point more fundamental than either spacetime or the quantum state, because comparison is the most elementary act of information. The cross-modal reach shows one more point: information is not a neutral substrate, since information has modal character. Researchers in some programs treat information as the common floor beneath both theories, the single basis from which both theories would follow. I expect the researchers to find that the floor has the same two conjugate aspects that the theories had, and that the researchers will then have to choose which aspect to perfect.

Finally, Noether's theorem is the cross-modal reach seen within classical physics. Noether's theorem says that every continuous symmetry of the dynamics yields a conserved quantity. The symmetry is omniscient, and the dynamics, the force in time, is immanent. So Noether's theorem is the omniscient's tool reaching into the immanent domain to produce the invariants that make the dynamics intelligible. The cross-modal reach appears in classical physics too, and the appearance of the reach in classical

physics is a sign that the reach is not peculiar to the two great theories. The reach is the general condition under which any tool describes any domain.

X. Summary

The central claim of this essay is that General Relativity and Quantum Mechanics cannot be unified in a single theory whose findings perfect both continuity and symmetry. The central claim is a structural exclusion: the claim says what physics will not find, and the claim says why. Four of the readings in this essay are readings of known results: the reading of each theory as one surviving conjunction, the reading of the existing programs as trade-offs, the reading of the problem of time as the reach applied to time, and the reading of complementarity and of Noether's theorem as instances of the same structure. Among the programs in which the arena is kept out of the quantum state, I do not say in this essay which program is nearer the truth. I do not say that either theory is wrong: each theory is right in its range, for a reason that also says why the ranges of the two theories cannot be made one.

Each fundamental theory of physics uses the structural tool of the modality opposite to the modality of its own domain. General Relativity uses continuity, the transcendent's tool, to describe the macroscopic, the omniscient domain. Quantum Mechanics uses symmetry, the omniscient's tool, to describe the microscopic, the transcendent domain. The reach across the modal divide is required. Self-application is semantically empty, so a domain cannot be informatively described by a tool of its own modal character. And the two modalities are conjugate, each giving an account of the other. The reach across the modal divide is what makes each theory powerful.

Each theory is one of the two surviving conjunctions of the Incommensuration Theorem. General Relativity is continuity with asymmetry. Quantum Mechanics is symmetry with discontinuity. A formalism that

was both survivors would perfect symmetry and continuity together. Symmetry with continuity is the one conjunction that comparison cannot make. The failure to unify the two theories is a structural exclusion, and not a problem awaiting a solution. The structural exclusion rules out the request for a single theory whose findings perfect both survivors. The coherent form of the request is already met.

The two theories are conjugate aspects of a single domain, and not competing descriptions of one reality. The two theories are related through the interaction in which both theories are brought to bear on a single event. No third theory above the two theories relates the two theories. Each theory captures what the other must leave out. The tool of each theory comes from one modality, and the theory uses the tool to describe a domain of the other modality, a domain whose modal character the tool cannot have. The reach across the modal divide is the power of each theory. The limit is that the two reaches cannot be combined into a single grasp: no single theory has findings that perfect both. The limit is not a limit of ours. The limit belongs to comparison itself.

KEY CONCEPTS IN THIS ESSAY

- **Cross-modal reach**: the pattern by which a theory's constructive principle belongs to the opposite modality from the domain the theory describes; General Relativity uses continuity (transcendent) for the macroscopic (omniscient), and Quantum Mechanics uses symmetry (omniscient) for the microscopic (transcendent).
- **Necessity of the reach**: self-application is semantically empty, so a domain cannot be informatively described by a tool of its own modal character; description requires a tool from a different modality.
- **Tool**: the character a theory perfects in its findings; the conjugate character is carried, exactly, in the theory's formalism; the modal character of the tool can and must differ from the modal character of the domain the theory is about.

- **General Relativity as continuity with asymmetry**: the smooth geometry that General Relativity finds is constitutive and absolute, the coordinate invariance of General Relativity is a symmetry of the formalism, and General Relativity generates asymmetry (curvature, horizons, the directed lightcone); the first survivor of the theorem, made physical.
- **Quantum Mechanics as symmetry with discontinuity**: the exact invariants that Quantum Mechanics finds are constitutive and absolute, the unitary evolution of Quantum Mechanics is continuous in the formalism, and Quantum Mechanics generates discontinuity (quantization, the discrete outcome); the second survivor, made physical.
- **Two levels**: a theory's formalism exists and the theory's findings are real; the theorem constrains which compound a theory perfects in its findings, and the theory's formalism carries the other compound; on the split between the two levels the two theories divide cleanly.
- **Unification as the forbidden conjunction**: a single theory whose findings perfect both survivors would perfect symmetry with continuity, which the theorem precludes; the exclusion is of impossibility, not of difficulty.
- **Partial trade-off**: any program of quantum gravity sacrifices some symmetry for continuity or some continuity for symmetry; the sacrifice is the signature of the theorem at work.
- **Gravity as context**: gravity is the shape of the context row of the six-measure grid, the curvature of the connectivity of the domain, and not a content within the domain; the reading is reached also by the four markers of a context; the quanta of the description of the small waves of gravity are quanta of a description only (the phonon is the nearest sense of the word, and the arena is not a held structure), and gravity has no particle, since every particle is a kind of content.
- **The immanent as the meeting**: what relates the two conjugate theories is the interaction, the measurement, in which both theories are brought to bear on one event; not a third formalism above the two theories.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.43-2, 1.43-3 (the Incommensuration Theorem); 1.43-6 (measurement as interaction); 1.85-8 (the six intrinsics of measurement).

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapter on the universal law.

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six measures.

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3. Chapters 5, 8 and 10.

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapters 3, 8 and 10.

Landry, Forrest. *Non-Commutative Geometry and the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-100-5. Chapters 13, 15 and 19.

Landry, Forrest. *The Unquantized Arena; A Structural Diagnosis of Quantum Gravity and the Measurement Problem.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-067-1. Chapter 14.

Chamseddine, Ali H., and Alain Connes. "The Spectral Action Principle." *Communications in Mathematical Physics* 186 (1997): 731–750.

Bohr, Niels. "The Quantum Postulate and the Recent Development of Atomic Theory." *Nature* 121 (1928): 580–590.

Butterfield, Jeremy, and Chris J. Isham. "On the Emergence of Time in Quantum Gravity." arXiv: gr-qc/9901024, 1999.

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

Isham, Chris J. "Structural Issues in Quantum Gravity." arXiv: gr-qc/9510063, 1995.

Jacobson, Ted. "Thermodynamics of Spacetime: The Einstein Equation of State." *Physical Review Letters* 75 (1995): 1260–1263.

Noether, Emmy. "Invariante Variationsprobleme." *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen*, 1918.

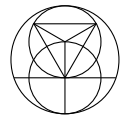
Penrose, Roger. *The Road to Reality: A Complete Guide to the Laws of the Universe.* London: Jonathan Cape, 2004. Chapters 30 to 34, on the interface of the two theories.

Rovelli, Carlo. *Quantum Gravity.* Cambridge: Cambridge University Press, 2004.

Smolin, Lee. *Three Roads to Quantum Gravity.* London: Weidenfeld & Nicolson, 2001.

Verlinde, Erik. "On the Origin of Gravity and the Laws of Newton." *Journal of High Energy Physics* 2011, no. 4 (2011): 29.

Wheeler, John Archibald. "Information, Physics, Quantum: The Search for Links." In *Proceedings of the 3rd International Symposium on Foundations of Quantum Mechanics*, Tokyo, 1989.



Essay 13

Three Kinds of Acceleration

On Convergence, Parallelism, and Divergence,
and What the Equivalence Principle Leaves Open

ABSTRACT

Albert Einstein's principle of equivalence states that, at a single point, the acceleration of gravity cannot be told apart from acceleration of any other kind. Over a region, the acceleration of gravity can be told apart from the other kinds. The kinds are told apart by what happens to the free paths of neighboring bodies. A free path is the path that a body follows when the body is released and left to itself. Neighboring free paths run together toward a common center, keep their separation, or run apart from a common axis. The three cases are the convergent, the parallel, and the divergent kinds of acceleration: the fall toward a mass, the push of a rocket, and the outward pull of a spinning platform. In this essay I argue that the partition into three kinds is exhaustive, because, seen from an accelerated frame, a family of free paths has a common locus ahead of the paths, nowhere, or behind the paths, and there is no fourth relation. An accelerated frame is a room, rocket or platform that is accelerating, from which an observer watches. A common locus is a point or a line that all the paths share. I then read the three kinds as the three modalities made physical. The Introduction sets out the three modalities: the immanent is the mode of process, the omniscient is the mode of structure, and the transcendent is the mode of the generative. The convergent kind is transcendent: it is fixed by what is outside the body, the context in which

every path lies. The parallel kind is immanent: it is the push at the point of contact, the exchange, the here and now. The divergent kind is omniscient: it is the relation of a frame to its own axis, structural, and knowable from the shape of the motion. The modal reading has a consequence for gravity. Of the three kinds, only the convergent kind cannot be produced for a free body by any local action. A local action is a push or a spin applied at one place. In the Introduction's terms, content is what is being compared, and context is the frame of the comparison. When I say that gravity is context rather than content, I mean that no local action produces the convergent kind: gravity is the shape of the setting, and not an act within the setting. In the Summary I say what kind of claim each of the three results is: the partition is a structural claim, and the modal reading is a reading of known physics. The claim that gravity is context is a structural exclusion that does not rest on the grid of the six measures alone.

Note on framework. This essay depends on the Introduction to this volume for the three modalities, the three axioms, and the modal alignment. The modal alignment is the assignment of the three modalities that I use throughout the book. This essay also depends on the essay on the six measures, in Part I, for the grid of content and context, in which I set out the six measures (mass, space, force, time, probability and possibility) in three columns and two rows. In this essay I develop, from the side of what a body feels, the reading of gravity as context that I stated from the side of theory in the essay on cross-modal reach, the essay just before this one. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. What the Equivalence Principle Leaves Open

The physicist Albert Einstein stated the first form of his principle of equivalence in 1907. The first form was a thought about a closed room. A person in a closed room feels a floor press upward. The room may stand on the surface of a planet, or a rocket beneath the room may be accelerating the room through empty space, but the person cannot tell which by any experiment performed at a single point. A person in free fall feels nothing. The room may be falling toward a mass, or the room may be drifting far from every mass with no force acting on the room at all, but at a single point the person in free fall cannot tell which. So the gravitational and the inertial are locally one: at a single point, the acceleration due to a mass cannot be told apart from the effects of the room's own motion, pushed by a rocket or drifting free. The founding physical idea of General Relativity is the local oneness of the gravitational and the inertial. Physicists could read gravity as the geometry of the domain, and not as a force acting within the domain, because of the local oneness. In this essay the domain is the space and time in which bodies move.

The principle of equivalence is stated for a point, and the principle is exact only at a point. Over a region, an observer can tell gravity apart from the other kinds of acceleration. Suppose the falling room is large enough. Objects released at the two sides of the room drift toward one another as they fall, because each object is headed for the center of the planet, and the center is one point. Objects released one above the other drift apart, because the lower object is nearer the center and falls faster. In the room in the rocket, an observer finds no drift between released objects. Objects released anywhere in the room keep their separation exactly. A room on a spinning platform is also a room whose floor presses on the person inside. On the spinning platform, released objects move outward from the axis, faster the further out they are, and curve as they go.

So the principle of equivalence says that the kinds of acceleration cannot be told apart at a point, but the principle also shows how the kinds are told apart over a region: by comparison. One body at one place feels only its own state. Two bodies, or one body at two times, show which kind of acceleration they are in by what happens between them. Observers tell the kinds of acceleration apart by comparison, and a claim of the same shape runs through the whole of this book. What is a fact at a single point becomes structure only when a comparison is made across difference of context. In the case of acceleration, a difference of context is a difference of place or of time. The three kinds of acceleration are the three things that an observer can find by comparison.

II. The Three Kinds

I name the three kinds by what each kind does to the free paths of neighboring bodies, because what happens to the free paths is what an observer in any of the three kinds actually finds.

The first kind is convergent: the convergent kind is the acceleration of gravity, the fall toward a center of mass. Every free body in the region is headed for the same point. The paths of neighboring bodies come closer to one another as the bodies go. The observer feels nothing, because free fall is weightless: in free fall there is no floor, no push, and no sense of motion. By comparison, the observer finds the tide. The tide is the slow drawing together of things released side by side, and the slow drawing apart of things released one above the other. The drawing together and the drawing apart are both signs of a single center toward which all the paths run. In empty space the tide squeezes a small cloud of released things in two directions and stretches the cloud in the remaining direction, with no change in the volume of the cloud at first. The tide produces a shear, a change of shape with no change of volume. The shear then focuses the

paths, which means that the shear draws the paths together. Where there is matter among the paths, the matter focuses the paths directly. Both kinds of focusing are the convergent kind (*Measurement*, Chapter 10).

The second kind is parallel. The parallel kind is the acceleration of a push: the rocket, the elevator, the floor of any room driven in a straight line. Every released free body in the region keeps its direction and its separation from every other free body, so the paths stay parallel, and the room accelerates past the paths. The observer feels weight: the floor pressing upward, the same everywhere in the room, the same at every height. By comparison, the observer finds nothing further: there is no tide. Released objects fall to the floor together and land the same distance apart as they began.

The third kind is divergent. The divergent kind is the acceleration of rotation: the spinning platform, the centrifuge, the frame that turns about its own axis. Once released, every free body in the region moves outward from the axis and never returns to the axis. Seen from the platform, the paths run apart from a common line. A body is thrown faster the further the body is from the axis. The observer feels an outward pull that grows with distance from the center, and the observer also feels a sideways deflection of anything that moves, so that a thrown ball curves. By comparison, the observer finds that the pull is not the same everywhere: the pull is zero at the axis and increases without limit outward. The outward pull differs from the push of the rocket in one respect alone: the outward pull varies from place to place, while the push of the rocket is the same at every place in the room.

The three kinds of acceleration are three experiential states, and I insist on the word "experiential". Each kind is a state that a body can be in, with its own feel and its own signature when a comparison is made, and so a pilot can tell the three kinds apart without an equation.

III. Why the Partition Is Exhaustive

I need an argument for the claim that there are three kinds of acceleration and not four, and the argument is short.

Consider a family of free bodies released together in a small region and observed from a frame that is accelerated in some way. Left to themselves, the free bodies follow the straightest paths available in the domain. Because the frame is accelerated, an observer in the frame sees the straightest paths as curved. The question is what shape the family of curves has. Either the family has a common locus, a point or a line that all the paths share, or the family has no common locus. If the family has a common locus, either the locus lies ahead of the paths and the paths run together toward the locus, or the locus lies behind the paths and the paths run apart from the locus. If the family has no common locus, the paths run parallel. Ahead, behind, or nowhere: the three cases are the whole of the possibilities, for two reasons. First, a shared locus for a family of paths is either in the future of the paths, in their past, or absent. Second, when a quantity must be less than, greater than, or equal to a given value, the quantity has three cases and no fourth.

Any actual acceleration field over a region is some combination of the three kinds. Picture a platform that spins while the platform falls toward a planet and a rocket pushes the platform sideways. A body on the platform is in all three kinds at once, so an observer who compares released bodies on the platform will find the signatures of all three kinds superposed. A combination of the three kinds is not a fourth kind: a combination is the three kinds inseparable in an instance. One should expect the classes of any partition in the metaphysics to be inseparable in an instance. The metaphysics is the account of comparison on which this book rests. Axiom III states that the classes and instances of the three modalities are distinct, inseparable, and non-interchangeable. Distinct: the three signatures are different and can be told apart. Inseparable: every actual case involves all

three kinds to some degree, if only the degree zero. Non-interchangeable: none of the three kinds can be made from the others. In Section V I say why non-interchangeability matters most.

I claim that the ways in which a family of free paths can relate to a common locus are three, and that the three kinds of acceleration are the experiential faces of the three relations. An experiential face of a relation is the relation as a body feels and finds the relation. I do not claim that every mathematical description of relative motion has exactly three pieces. Physics has its own decomposition of relative motion. The physicist Amal Kumar Raychaudhuri found an equation, Raychaudhuri's equation, that describes how a cloud of free paths swells or shrinks. The terms of Raychaudhuri's equation match the three kinds. When there is no curvature, shear or rotation, the paths keep their separations: the parallel kind. Matter and the tidal shear focus the paths: the convergent kind. Rotation spreads the paths: the divergent kind (*Measurement*, Chapter 10). So my partition is a partition of kinds of relation, and not of terms in a formula.

IV. The Modal Reading

I set out three modalities in the Introduction to this volume. The omniscient is the structural, the repeatable, the shareable, the third-person: existence, pattern, law. The immanent is the processual, the relational, the interactive, the here and now: interaction, change, reality. The transcendent is the evaluative, the creative, the potential, the generative: choice, possibility, principle. I add a further triple at aphorism 1.85-4 of my book *An Immanent Metaphysics*: causality is omniscient, change is immanent, and choice is transcendent. Each of the three kinds of acceleration goes into one of the three modalities without strain. Sorting the three kinds into the three modalities is what this essay is for.

Axiom I states: "The immanent is more fundamental than the omniscient and/or the transcendent. The omniscient and the transcendent are in conjugate relationship to one another" (*An Immanent Metaphysics*, aphorism 1.3-1). When Axiom I is read in the triple of the three kinds, linear acceleration (immanent) is more fundamental than either gravitation (transcendent) or rotation (omniscient). Gravitation and rotation are then the conjugate pair: the many to the one and the one to the many, the paths running together toward a center and the paths running apart from an axis. I offer the reading of Axiom I in the triple of the three kinds as an identification, and not as a theorem of mechanics. Acceleration is the quantity in which all three kinds are expressed. In each kind, the force a body feels is proportional to the body's inertial mass, the mass that resists a change of motion. So each kind is fully described by an acceleration, which is the force per unit of inertial mass. The Newtonian field of gravitation is the acceleration that sources of mass produce in a free test body, which is a body small enough that its own mass does not disturb the setting. The curvature of spacetime is observed as the relative acceleration of neighboring free bodies. For a body moving at speed v on a circle of radius r, the centripetal acceleration is v^2/r, fixed by the speed and by the curvature of the path. The second law of the physicist Isaac Newton is $F = ma$ (force equals mass times acceleration), and so the second law places acceleration at the center: every force is a mass times an acceleration. Physics states both gravitation (the transcendent kind) and rotation (the omniscient kind) in terms of the immanent concept, acceleration as such, whose plainest instance is the push. So my assignment of the kinds is consistent with Axiom I, which says that the immanent is more fundamental than the omniscient and the transcendent.

The convergent kind is transcendent. For a test body, the convergent kind is fixed entirely by what is outside the body: by the distribution of mass and energy in the whole surrounding region. No push applied to the body alters the distribution of mass and energy, and the distribution exceeds any local specification, that is, anything that can be stated about one place alone. The convergent kind is the same for every body, whatever

the body is made of. The convergent kind is the acceleration in which the body does nothing at all. Free fall is the body simply existing in a domain whose shape is given. The convergent kind is the many to the one: every path in the region runs to a single center, the same for all the paths. And the convergent kind is context: potential and environmental, the setting within which both trajectories and interactions occur.

The parallel kind is immanent: the parallel kind is the push, a force applied at a point of contact, felt as weight, here and now. The parallel kind exists only while the interaction continues: the moment the rocket's engine stops, the parallel kind is gone. The parallel kind is exchange: the rocket accelerates by throwing mass out behind the rocket. The acceleration of the rocket is the other side of the exchange. The parallel kind is one to one: a body and what pushes the body, in direct relation. Meanwhile the free paths around the body stay in the relation they had. And the parallel kind is change, the alteration of a state by an interaction, which I assign to the immanent in *An Immanent Metaphysics*. In the six-measure grid of the companion essay, the immanent column is force in time. The parallel kind is force in time and nothing else.

The divergent kind is omniscient and structural: it is the relation of a frame to its own axis. The divergent kind is fixed by the knowable shape of the motion: the curvature of each path about the axis, the pattern of the motion. The divergent kind needs no external mass and no continued push. A platform once spun keeps spinning, and the outward pull persists without anything further being done. The divergent kind is the one to the many: from a single line, paths radiate into every direction, and the outward pull grows without limit as one moves outward from the axis. Newton found that the divergent kind can be detected from inside, without any comparison to the outside, and Newton made the point in the scholium (an explanatory note) on the spinning bucket. The physicist and philosopher Ernst Mach objected that the distant stars might matter after all to whether a body rotates, and the question Mach raised has never been fully settled. But the phenomenology is not in doubt: the phenomen-

ology is what an observer on a spinning platform feels and finds. Rotation is the acceleration that knows itself: an observer can find the rotation of the observer's own frame from inside the frame.

> **On the Direction of the Reading**
>
> The modal reading is a reading, in the sense the Introduction gives the word: in a reading I take a result that physics has already established, and I read the result as an instance of the structure of comparison. The partition into three kinds depends on the trichotomy of Section III (ahead, behind, or nowhere) and does not need the modalities. I gain from the modalities a reason why the three kinds should be these three: the three modalities are the same three modalities that appear in the structure of comparison, interaction, and measurement everywhere else in this book. To my mind, the modal reading is confirmed by how little has to be forced. The three kinds could have sorted the other way: the push could have turned out to be the kind fixed by the world, or the fall the kind that radiates. If the three kinds had sorted the other way, I would have taken the sorting as evidence against the modal alignment. The three kinds did not sort the other way.

V. Gravity as Context

The point that matters most is the one Axiom III calls non-interchangeability. None of the three kinds can be made from the others. And one of the three kinds cannot be made at all by anything a body does.

Two senses of "curvature" must be kept apart in this section. The curvature of a trajectory is a property of a path: a body moving at speed v on a circle of radius r has the centripetal acceleration v^2/r, in flat spacetime as in curved. The curvature of spacetime is a property of the arena, the space and time in which every path lies. General relativity replaces the gravitational force with the curvature of spacetime, and the observable signature of the curvature of spacetime is the relative acceleration of

neighboring free bodies, the tidal effect (*The Gravitational Passage*, Chapter 15, Section V). Rotation and its centripetal force belong to the first sense of curvature, and gravitation belongs to the second sense. General relativity does not identify the two senses. So general relativity does not treat rotation and gravitation as one thing.

The parallel kind is made by a push, and any body can produce the parallel kind for itself, given something to push against. The divergent kind is made by a spin, and any body can produce the divergent kind for itself, given something to spin against. Once produced, the divergent kind needs no further action. The convergent kind cannot be produced by a body at all. No push, applied anywhere, to anything, causes the free paths of neighboring bodies to run together toward a common center. A push moves the thing pushed. A push does nothing to the paths of free bodies that are not pushed, and convergence is a fact about the paths of free bodies. One can push each of a family of bodies separately and aim all of the bodies at a point, but the aimed bodies are then in many parallel accelerations that imitate one convergent acceleration. The imitation fails the moment a body that was not pushed is added: the added body will not converge. The convergent kind belongs to the free paths themselves, to the shape of the domain in which the free paths lie. No push applied to one body reshapes the free paths of the other bodies. The setting is shaped by the content in the setting, which is the mass and energy of the region.

When I say that gravity is context rather than content, I mean that the convergent kind belongs to the shape of the domain, and that no push produces the convergent kind. In the six-measure grid of the companion essay, the six intrinsics of measurement (the six measures) are in two rows. One row is content: mass, force, and probability, governed by symmetry law. Symmetry law is the law of sameness of content across difference of context. The other row is context: space, time, and possibility, governed by continuity law. Continuity law is the law of sameness of content within sameness of context. A push is content acting on content: force applied to mass. A spin is a frame's relation to its own axis, the shape of a motion held in a state. But the fall is not in a cell of the grid. The fall is the

shape of the context row, the curvature of the space and time in which mass and force are related to their setting. The fall is what all contents share alike, and what all contents share alike is not a content. The fall is the setting.

General Relativity also says, in its own terms, that gravity is the setting. In General Relativity, gravity is not a force: free fall is inertial motion, and what we call the force of gravity is the floor pushing up, which is the parallel kind, felt because the floor prevents the fall. The convergence of free paths is the curvature of the geometry, and the curvature is fixed by the distribution of mass and energy, which is to say by what is outside any given body. I read what General Relativity says as physics arriving, by its own route, at the place I give gravity in this essay: gravity is the form of the domain, and not an occupant of the domain. I set out a consequence of gravity being context in the essay on cross-modal reach: gravity has no particle and no quanta. A description of the small waves of gravity has quanta, and those quanta are quanta of the description only, and not quanta of gravity. The three kinds of acceleration are a ground of their own for the reading of gravity as context, independent of the grid. The convergent kind is the one kind that no local action produces, and a thing that no local action produces is hard to read as something that travels from one place to another.

I have one last thing to say about the principle of equivalence, in the light of the reading of gravity as context. The principle says that at a point the fall and the push are one. On the reading of gravity as context, the principle states that at a point, without comparison, context and content cannot be told apart. A body with nothing to compare feels the shape of the setting and an act within the setting as the same. Over a region, an observer can tell the shape of the setting from an act within the setting, because a region admits comparison across difference of context, and a difference of context is where the context shows itself to an observer who compares.

VI. Summary

I claim that the three kinds of acceleration are the three modalities made physical, and the claim is a reading of known physics. In the modal reading I give the structural reason for the form of the equivalence principle, and for the way the three kinds of acceleration come apart over a region. The claim that the partition is exhaustive is a structural claim. The claim rests on a trichotomy of how a family of free paths relates to a common locus. A third claim is a structural exclusion: gravity is context rather than content, and gravity will not be made a force among forces. A structural exclusion says what physicists will not find, and says it structurally, not numerically. In this essay I argue that General Relativity is right about gravity. I also say what, on the reading of this essay, General Relativity is right about.

At a point, all acceleration is one. Over a region, acceleration is of three kinds: the free paths of neighboring bodies run together, run parallel, or run apart. The fall, the push, and the rotation are the three kinds, and there is no fourth, because a family of paths has its common locus ahead, nowhere, or behind.

The three kinds are the three modalities. The fall is transcendent: set by what lies beyond the body, the context in which every path lies, the same for everything, the many to the one. The push is immanent: an exchange at a point of contact, felt as weight, here and now. The rotation is omniscient: a frame's relation to its own axis, structural, and knowable from the shape of the motion, persisting without further action, the one to the many. The three kinds are distinct, inseparable, and non-interchangeable, as the third axiom says the modalities are, and the kind that cannot be made is the kind that is the shape of the setting.

On the reading of this essay, gravity is the shape of the setting. Gravity is not a content among contents and not an act within the domain, but the form of the domain in which every content and every act finds its path.

The principle of equivalence began as a thought about a closed room. The principle turns out to say what the metaphysics says about content and context everywhere: alone, at a point, content and context cannot be told apart, and comparison, across difference of context, is where the difference between content and context appears.

KEY CONCEPTS IN THIS ESSAY

- **Convergent acceleration**: the fall toward a center of mass; the free paths of neighboring bodies run together toward a common point; felt as weightlessness with tide; transcendent.
- **Parallel acceleration**: the push of a rocket or a floor; the free paths of neighboring bodies keep their separation; felt as uniform weight; immanent.
- **Divergent acceleration**: the outward pull of rotation; the free paths of neighboring bodies run apart from a common axis; felt as a pull that grows with distance from the axis; omniscient.
- **Exhaustiveness of the partition**: a family of free paths has its common locus ahead, behind, or nowhere; three cases and no fourth; any actual acceleration is a combination of the three.
- **The equivalence principle as comparison**: at a point the three kinds are one; over a region they come apart by comparison across difference of context.
- **Non-interchangeability**: none of the three kinds can be made from the others, and the convergent kind cannot be produced for a free body by any local action.
- **Gravity as context**: the convergent kind is the shape of the context row of the six-measure grid, the curvature of space and time, and not a content acting within the domain.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms); 1.85-4 (causality, change, and choice); 1.85-8 (the six intrinsics of measurement).

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six measures.

Einstein, Albert. "Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen." *Jahrbuch der Radioaktivität und Elektronik* 4 (1907): 411–462.

Einstein, Albert. "Die Grundlage der allgemeinen Relativitätstheorie." *Annalen der Physik* 49 (1916): 769–822.

Newton, Isaac. *Philosophiae Naturalis Principia Mathematica.* London, 1687. The scholium to the definitions, on absolute and relative motion.

Mach, Ernst. *Die Mechanik in ihrer Entwickelung, historisch-kritisch dargestellt.* Leipzig: Brockhaus, 1883.

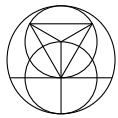
Raychaudhuri, Amal Kumar. "Relativistic Cosmology. I." *Physical Review* 98, no. 4 (1955): 1123–1126.

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapter 10 (the markers of context; the three readings of inertia and Raychaudhuri's equation).

Landry, Forrest. *The Gravitational Passage; Deriving General Relativity from the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-056-5. Chapter 15, Section V (the tidal effect as the signature of the curvature of the context).

PART IV

The Boundaries of Physics



Essay 14

The Three Horizons

The Macroscopic, the Microscopic, and the Surface of Unconsciousness, as Classes Rather Than Instances

ABSTRACT

Physics has two edges, and the knowing self has a third. The speed of light marks the macroscopic edge, the edge of the very large, and no signal arrives from beyond that edge. Planck's constant marks the microscopic edge, the edge of the very small: below the limit that Planck's constant marks, no measurement distinguishes jointly what a pair of conjugate quantities, such as position and momentum, would need to fix. The third edge lies inward, at the mesoscopic scale of the self, between the very small and the very large, and the third edge is the surface of unconsciousness, past which the self cannot see itself. I read the three edges as horizons rather than walls. Each horizon recedes as it is approached, and each horizon marks the place where the unknown gives way to the unknowable. Each horizon is temporary as an instance and permanent as a class. An instance is the horizon as one knower comes up against it at one place and time. The class is the kind of boundary that every instance is. I distinguish Planck's constant, whose number expresses a unit, from the microscopic limit, which is Planck's constant read as a boundary of a domain. And I say why the Planck length is no least length. I locate the two physical horizons as the two constants that bound the domain of comparison. The domain of comparison is everything that can be compared, and so measured. The speed of light marks a limit from the outside, and

Planck's constant marks a limit everywhere within. I read the nonlocality of entangled systems as the curvature of a domain rather than as a paradox. And I apply the Incommensuration Theorem to the black hole. The event horizon of a black hole is one-way by the smooth tipping of every cone. Smoothness is continuity and one-wayness is asymmetry, so the event horizon is continuity with asymmetry, which the theorem permits. General relativity describes a singularity that conjoins perfect asymmetry with perfect discontinuity, which the theorem forbids, so on the framework of this book I expect that physics will not find the singularity realized as described. I close by saying what kind of claim each claim of this essay is.

Note on framework. This essay depends on the Introduction to this volume for four things: the six intrinsics, the Incommensuration Theorem, the three axioms and the modal alignment. This essay also depends on the essay on causation, connectivity and the domain boundary, in Part III, which treats the macroscopic boundary at length. Two essays follow this essay immediately. In the essay on domain constants I develop the two physical horizons as a pair that bounds every domain, and in the essay on the microscopic boundary I develop the lower horizon as the physical face of quantum indeterminacy. In *Unlocking Reality*, in the chapter on the limits of the epistemic process, I give the general argument that a theory cannot be continuous with what the theory describes, and in this essay I build on that argument without restating it. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Unknown and the Unknowable

In science as it is ordinarily practiced, scientists recognize two categories of things, the known and the unknown, and scientists understand the unknown as the not-yet-known. On this ordinary view the unknown is a frontier, and the whole method of inquiry is a way of pushing the frontier

back: each inquiry turns some of the unknown into the known. So on this view what is known today and what will be known tomorrow differ only in effort, instrumentation and time, and not in kind.

The framework of this book has a third category, the unknowable. The unknowable is that which cannot be known, even in principle, by any observer, at any time, by any method, because the structure of comparison itself does not extend to the unknowable. So the unknowable is not the merely unknown, and the unknowable is not a gap in current knowledge awaiting future discovery. There is a place where logic does not pass, a place where no amount of experience will ever yield the thing sought. At that place the unknown stops and the unknowable begins. The line between the unknown and the unknowable is the line between ordinary knowing and the Great Mystery, which is my name for the convergence of the unknown and the unknowable. The Great Mystery has three forms, and the three forms are the three horizons of this essay. The first form is the Mystery of the Horizon, at the macroscopic limit, the limit of the very large. The second form is the Mystery of the Infinitesimal, at the microscopic limit, the limit of the very small. The third form is the Mystery of the Subconscious, at the mesoscopic limit, the limit at the scale of the self, which in this essay I call the surface of unconsciousness (*Comparison*, Chapter 11, Section V).

The three categories of knowledge match the three modalities (the omniscient, the immanent and the transcendent) in the modal alignment that I fix for this whole volume in the Introduction. The known has the nature of the omniscient: the known is complete, available and inspectable, like a photograph whose every part can be seen. The unknown has the nature of the immanent: the unknown is the process of coming to find out, perception in the here and now, which gives a view of things without giving the totality of things. The unknowable has the nature of the transcendent: the unknowable is what exceeds every capture, what has no fixed shape or pattern by which a description could bring the unknowable within the description. The three correspondences are more than decorative. The omniscient is the mode of structure and completeness. The immanent is the

mode of process and becoming. The transcendent is the mode of excess and creation. Each category of knowledge is what it is because the category has the character of the modality that corresponds to the category.

In this essay I add that the unknowable has a shape, and so the unknowable is not one thing. The knowable gives way to the unknowable in exactly three places, and two of the three places are the boundaries of physics. I describe the three places in the rest of the essay, I say why the places are three, and then I follow the two physical horizons into the results that physics has found at the two horizons.

II. The Horizon of the Macroscopic

The first boundary is the limit of the very large: the boundary beyond which nothing can be perceived, however far one travels and however sensitive one's instruments become, and in physics the limit of the very large is expressed through the speed of light. I quote the value of the speed of light only as a description: a little under three hundred thousand kilometers per second. Nothing in this essay depends on that value. Nothing crosses from one event to another faster than light: no signal, no information and no causal influence. The familiar picture is the lightcone: from any event one cone opens outward into the future and another opens backward into the past. In principle, one can know from an event whatever lies within the two cones of the event, while one cannot know from that event whatever lies outside the two cones, and physicists call the region outside the two cones the absolute elsewhere.

I argued three things in the essay on causation and connectivity, in Part III. I argued that the speed of light is the macroscopic boundary of the domain of comparison, and is not, at root, the speed of any one thing, and I argued that space is nothing other than the connectivity structure of which events can affect which. I take that argument as read, and here I draw out a feature of the macroscopic boundary that the argument implies and that the essay in Part III did not dwell on.

The macroscopic horizon recedes as one approaches the horizon. So the horizon is not a wall, not a thing that one can approach and touch. An instance of the horizon is the horizon as it is for one particular event: the edge of the lightcone of that event. One overcomes any particular instance of the horizon by moving toward the instance, or simply by waiting: what was beyond the lightcone of one event enters the lightcone of a later event. So the elsewhere of yesterday is the past of today. But a new horizon always appears, because there is no later event whose cone contains everything. In a universe whose expansion accelerates, as the expansion of our universe does (Riess and others, 1998; Perlmutter and others, 1999), some events will never enter the past lightcone of a given observer, at any time. The boundary of the events that will never enter the past lightcone of a given observer is the boundary that physicists call the cosmological event horizon. The horizon as an instance is temporary, while the horizon as a class, the kind of boundary that every event has, is permanent, and the class, not any instance, is the boundary of the knowable.

The macroscopic horizon as a class is the first form of the Great Mystery, the Mystery of the Horizon. From any position there is always a beyond of the horizon's instance: something that exceeds what can be known from where one stands. The specific beyond changes as one moves. For the horizon as a class, which is the boundary of the knowable itself, the word "beyond" is not defined. The reason is that the limit that the Incommensuration Theorem sets is "the curvature of the field itself, rather than a wall at the edge of an otherwise open field" (*Incommensuration; The Theorem and the Three Axioms*, Chapter 6, Section XI). One who moves changes the instance of the horizon and never the class.

III. The Horizon of the Microscopic

The second boundary is the limit of the very small: the finest scale at which measurement is possible, the domain of quantum mechanics. Physics expresses the limit of the very small through Planck's constant and

through the uncertainty relation that carries the name of the physicist Werner Heisenberg. Planck's constant has the units of action: a momentum times a distance, or an energy times a time. So Planck's constant cannot by itself set a length or a duration. How fine a comparison can be made depends on the energy brought to the comparison.

Two things are easily run together here, and I want to be careful to keep the two apart: Planck's constant and the microscopic limit. Planck's constant is a number, and the number expresses a unit. The microscopic limit is Planck's constant read as the location of a boundary.

The Constant and the Limit

The uncertainty relation states that position and momentum cannot both be pinned down perfectly at once. The product of the two spreads is never less than half the reduced Planck constant, as the physicist Earle Kennard proved (Kennard, 1927). In that sense the uncertainty relation limits how much can be known about a physical system at once. The canonical statement concerns a particle with a position (since the particle is somewhere) and a momentum (since the particle moves somehow). One has some uncertainty about where the particle is and some uncertainty about how fast and in which direction the particle moves. Neither uncertainty is a hard edge. Each uncertainty is the width of a distribution of possible outcomes. The physicist Max Born gave the rule, called Born's rule, that states the probability of each outcome from the state. By Born's rule the distribution of outcomes belongs to the state itself, so the width of the distribution is not a property of the instrument. The smallest product of the two widths belongs to Gaussian states, whose spread has the bell shape of the normal curve. The point of the relation is that the two widths can be given a concrete number. The relation then says that the product of the two uncertainties cannot fall below a quantity fixed by Planck's constant, so if one narrows one of the two uncertainties, the other uncertainty widens. So far the relation is a number and a rule about a number. The relation becomes a limit, a boundary of the domain, only when one asks what happens as the position is narrowed without bound.

The passage from number to boundary goes as follows, as the physics literature itself makes the passage. I offer the passage as a reading of that literature, not as something the metaphysics (the account of comparison on which this book rests) supplies. As one pins down where a particle is to a smaller and smaller region, the uncertainty in the momentum of the particle grows, and since a larger momentum means a larger kinetic energy, the uncertainty in the kinetic energy grows too. Confine any measurable mass to a small enough region, and the uncertainty in the energy of that mass becomes enormous. Energy curves space as mass does, by the equivalence of mass and energy. So there is a scale at which the energy is enough to curve the space in which the measurement is being made so severely that the region closes on itself. The measurement would create a black hole larger than the region that the measurement set out to probe, and that black hole sets a bound on how sharply a comparison made from inside the world can place a body. The bound is a bound on findings, on what one can find by a comparison, and not a least step of space and time. Physicists call the scale at which the measurement would create a black hole the Planck scale. At the Planck scale a body's gravitational size, the size of the black hole that the body's mass would make, equals the body's quantum size, the spread in position that the uncertainty relation gives the body. At the Planck scale, too, the description of context and the description of content exchange dominance (*Measurement*, Chapter 7): on one side of the Planck scale one description dominates, and on the other side the other description dominates.

The Planck scale is built from Planck's constant, the speed of light and Newton's constant, the constant of Isaac Newton's law of gravitation. I quote the Planck length from the literature: the Planck length is of the order of ten to the minus thirty-five meters. The Planck length is no least length of the arena, the space and time in which every physical event takes place. Gamma-ray bursts are brief flashes of very energetic light from far galaxies. Light from distant gamma-ray bursts arrives together across very different colors (Abdo and others, 2009). If a grain of space slowed light in proportion to the energy of the light, the different colors

would arrive at different times, so the observations already place any such grain below the Planck length. The microscopic limit marks a bound on joint knowledge, and not a least length: below the action that Planck's constant marks, no measurement distinguishes jointly what a pair of conjugate quantities, such as position and momentum, would need to fix. The microscopic limit is a structural feature of the physical domain, and not a limitation of instruments.

And the microscopic limit recedes, as the macroscopic horizon does. As instruments improve, what was once too small to observe becomes accessible, and over history the accessible scale has descended by many orders of magnitude, that is, by many powers of ten. But there is always a scale below which observation stops. The instance of the microscopic limit moves, but the class persists.

One more point about Planck's constant belongs here, because I need the point in Section VI, where I set the two horizons side by side. As a number written in a theory, Planck's constant is known structure (a fixed and shareable pattern), and in that frame Planck's constant is omniscient. The number itself expresses only the unit in which action is measured. But one can also use the number to express where the boundary of the domain lies in terms of scale. In that use Planck's constant takes on a transcendent function relative to the speed of light, the other constant that also marks a boundary. The number is the same in both uses, read in two contexts, and this essay is about the second reading.

IV. The Surface of Unconsciousness

The third boundary is subjective rather than objective. The third boundary lies neither at the largest scale nor at the smallest, but at the mesoscopic scale, the scale of the self. The third boundary is the surface of unconsciousness.

When one looks inward, seeking to know oneself, awareness fails at some point, and at that point one becomes unconscious with respect to some part of oneself. So the process of coming to know oneself is never complete.

Light cannot perceive itself: through the electromagnetic field alone, light does not act on light. Two laser beams cross in space, and the wavefronts of the two beams go right through one another, unchanged, because the photon, the particle of light, carries no electric charge. Light carries the act of comparing between charged things, and the comparing act is not one of the things that the act compares. (Light does act on light through charged pairs, but so slightly that no lamp or laser makes the effect large enough to see. Physicists saw the effect with the ATLAS detector at the Large Hadron Collider at CERN: ATLAS Collaboration, 2017 and 2019.) In the same way, I cannot perceive the perceiver or perception. I can perceive only what is the object of perception. Of the three phenomena (perceiver, perceived, and perceiving) perception can perceive only the perceived. So we must study the relationship itself, the relation among perceiver, perceived and perceiving.

The incompleteness of self-knowledge is structural, and not a matter of insufficient diligence in looking inward. To know itself completely, a self would need to be both the knower and the known: symmetric with itself as pattern and continuous with itself as process, and the Incommensuration Theorem, which I state in the Introduction to this volume, forbids perfect symmetry and perfect continuity at once.

As awareness approaches the surface of unconsciousness, the surface recedes, in exactly the way the macroscopic horizon recedes before a traveler. There will always be aspects of the self remaining to be discovered. Self-knowledge deepens, but self-knowledge does not become total. The unconscious is a dynamic boundary, a class rather than an instance. The unconscious is not a fixed region of the psyche, a territory that could in principle be fully mapped.

I include the surface of unconsciousness in a book about physics for two reasons. The first reason is that the surface of unconsciousness shares every structural feature of the two physical horizons. The sharing is a consequence, as I argue in the next section. The second reason is that physics is done by selves, so the boundary of what a self can know of itself is a boundary of what any measurement, by any physicist, can report. Measurement is interaction, as I argue in the essay on measurement in Part I. The interaction has two sides, and one side of the interaction is a self that does not fully see itself.

V. Classes, Instances, and the Law of Three

The three horizons have three features in common: all three horizons are dynamic, all three are permanent as classes, and all three mark the point where the unknown gives way to the unknowable.

First, all three horizons are dynamic: each horizon moves as one approaches it. The lightcone of a later event contains what the lightcone of an earlier event could not contain. Better instruments resolve what earlier instruments could not resolve. Deeper attention brings to light what was earlier unconscious. So none of the three horizons is a wall, and none of the three horizons is a place.

Second, all three horizons are permanent as classes: the type of limit persists even as every particular instance of the limit dissolves. No later event has a cone that contains everything. No instrument reaches a scale beneath which there is no scale. No self completes itself. At this point in the essay the distinction between class and instance does real work, and I want to make the distinction explicit. I define the absolute boundary between the unknown and the unknowable in terms of classes. I define the relative boundary in terms of instances. The relative boundary is the boundary that a given observer comes up against from a given position at a given time. The relative boundary can always be crossed. The absolute boundary is never crossed, because to cross any instance of the absolute

boundary brings one to another instance of the same class. In the terms of this volume, the absolute has the nature of the omniscient, perfect and unchanging. The relative has the nature of the transcendent, moving and exceeding. The act of approaching a boundary is neither absolute nor relative in itself, and the act of approaching has the nature of the immanent.

A different question is what is absolute within each modal perspective. In the omniscient perspective the frame of reference is absolute. In the transcendent perspective the material is absolute. In the immanent perspective relation itself is absolute. This second assignment is about what is fixed within each perspective, and not about the boundaries of knowledge, so the second assignment does not conflict with the assignment of the absolute and the relative that I made in the paragraph before.

Third, all three horizons mark the point where the unknown gives way to the unknowable. Short of a horizon lies what is not yet known but could be. At the horizon lies what could not be known from here, by any means. The qualifier "from here" is what makes the boundary a horizon rather than a wall.

Why are there three horizons? The macroscopic and the microscopic horizons are objective, and the surface of unconsciousness is subjective. The count of two objective horizons and one subjective horizon follows a structural principle that recurs throughout the framework of this book. The principle is a triplication theorem grounded in the Law of Three. The Law of Three says that a relation is always a relation of at least three (*Comparison*, Chapter 9). The triplication theorem says that for every way in which something is subjective, there are two ways in which the thing is objective, and likewise, for every way in which something is objective, there are two ways in which the thing is subjective. The triadic structure of two and one appears at every level of the analysis, and the three horizons are one instance of the triadic structure.

The triplication principle is not arbitrary, because the principle comes from the six intrinsics of comparison, as I lay them out in the Introduction. The six intrinsics are the six features of every act of comparison: sameness

and difference, content and context, and the subjective and the objective. Every content has a context, and every sameness has a difference. Three is the smallest number of distinct elements that can satisfy these two requirements while remaining mutually irreducible, that is, while no one of the elements can be reduced to the others. Two elements can be same or different, but the sameness or difference of the two elements needs a third element from which to be seen. Among the six intrinsics, the subjective and the objective are the pair that supplies the seeing: the subjective is the standpoint from which a comparison is made, and the objective is what the comparison is about. And the third axiom says that the three modalities are distinct, inseparable, and non-interchangeable, so wherever one of the three modalities appears as a boundary, the other two modalities must appear as boundaries too. There is no fourth horizon, because there is no fourth modality. Nor are there only two horizons, because two horizons would leave one of the three modalities without an edge. A modality without an edge would be a modality in which the unknowable did not appear, and so a modality in which everything is knowable, and the Incommensuration Theorem precludes a modality in which everything is knowable.

On Absolute Statements

The same triadic structure of two and one shows why absolute claims about knowledge refute themselves. Consider the statement "everything is permissible and nothing is true". As a working tool for exploring perception and changing beliefs, the statement has power. But when the statement is applied as a categorical statement, true without exception, the statement undermines itself. Is the statement itself absolutely true? If the statement is absolutely true, then at least one thing is true, and the statement refutes itself. Likewise, the claim "Everything is knowable" is contradicted by the unknowable. And the claim "Nothing is certain" is contradicted by its own certainty. Each paradox comes from working with only two categories, true and false, or absolute and relative. The resolution is to identify a third class of conception, and not to choose one horn

> of the dilemma. A conception of the third class falls under neither truth nor falsity, but under a different kind of concept altogether: the immanent act of finding out. A framework is free of these paradoxes only if the known, the unknown and the unknowable are distinct categories in the framework, and the three axioms have their strength in that third class of conception.

VI. The Two Constants as the Boundaries of the Domain of Comparison

I now set the two physical horizons side by side. I call the constant that marks the microscopic horizon the H constant, and the constant that marks the macroscopic horizon the C constant. In this universe the H constant is Planck's constant, and the C constant is the speed of light. I use the two new names in order to speak of the two constants as the boundaries of any domain, rather than of this universe alone, and I develop that generality in the essay on domain constants, which follows this essay. Here I want only the relationship between the two constants.

The C constant marks a limit from the outside. The C constant defines which positions are too far away for anything about those positions to be known from here. The C constant relates space to time by one ratio, which is the same throughout the domain, though space and time stay distinct. Because space and time are related by one ratio, each comparer, each one who makes a comparison, has a horizon in space and time. When a comparer reconstructs the history of the domain from inside the domain, the history has a beginning, and nothing has arrived from past the horizon of the comparer, or can arrive. The C constant is therefore the omniscient limit of the domain, on the side of context: the farthest extent of the pattern of connection.

The H constant marks a limit everywhere on the inside: the limit that the H constant marks is present at every point, at the smallest scale of every measurement made anywhere, and is not far away. The H constant

defines which distinctions are too fine for anything about those distinctions to be known. The H constant is therefore the transcendent limit of the domain, on the side of content: the finest grain of what can be distinguished.

The C constant and the H constant are therefore two distinct boundaries, and not merely two numbers. The C constant marks a boundary that one comes to by going outward, while the H constant marks a boundary that one comes to by going inward, and that one can come to from any point. Between the two boundaries lies everything that is knowable as content within the domain, which is to say everything that is physics. And each of the two boundaries is the same kind of thing: a transition from the potentially knowable into the definitely unknowable. I call a transition of that kind a gateway. The microscopic limit and the speed of light are both gateways. Each gateway is a place where the physics stops, and neither gateway is a place where the physics becomes hard.

The Incommensuration Theorem says what to expect at each gateway, and I state the two expectations explicitly, because the two expectations differ. At the microscopic limit, where symmetry is asked for absolutely, as the finest and most repeatable distinction, the theorem says that one will find discontinuity: the granularity of the quantum, the discrete eigenvalue, the outcome that cannot be refined further. An eigenvalue is one of the separate values a measured quantity can take. At the macroscopic limit, where continuity is asked for absolutely, as the unbroken extension of the pattern of connection, the theorem says that one will find asymmetry: the lightcone that opens one way, the horizon that is crossed from one side only, the past that is fixed and the elsewhere that is not. In physics the unknowable is located at the extremes of scale for exactly this reason: a demand for perfection is made at the extremes, and the theorem says that a complete specification is impossible where perfection is demanded. The framework shows where these limits are, and the framework does not describe what lies past the limits.

I add one clarification here, which I make at length in the essay on the six measures in Part I. Space, time, and possibility are the context measures. The C constant bounds the context measures, and at the macroscopic limit the context measures must be continuous. Pattern, force, and probability are the content measures. The H constant bounds the content measures, and at the microscopic limit the content measures must be quantized. The units of the two constants agree with this division. The speed of light is a ratio of two context measures, a distance over a time. Planck's constant is a product of a content measure with a context measure: a momentum times a distance, or an energy times a time. So the C constant is on the side of context. The H constant joins content to context at the scale where content ceases to be divisible. The uncertainty relation is the statement that, at that scale, a content and the context of the content cannot both be fixed beyond the bound that the H constant sets. The units of the two constants thus carry the framework's reading of what each constant is a constant of. The essay on the six measures sets out a grid of roles. In the grid, each measure has a modal role (omniscient, immanent or transcendent) and a row (content or context). In the grid of roles, Planck's constant is the bridge between the immanent and the transcendent: Planck's constant connects time, the immanent context measure, with possibility, the transcendent context measure (*Measurement*, Glossary).

VII. Nonlocality as Domain Curvature

A domain bounded by the two constants has a property that shows itself in one of the most discussed results in physics, and I want to read that result in the terms of the framework.

When two systems are prepared together and then separated, a measurement on one system is found to be correlated with a measurement on the other system more strongly than any explanation by properties that each system carries separately allows. Three physicists described this situation in order to argue that quantum mechanics was incomplete: Albert

Einstein, Boris Podolsky and Nathan Rosen. The physicist John Bell then proved Bell's theorem, and Bell's theorem and the experiments that followed it turned the situation into a result about the world rather than about the theory. I develop that result as an instance of the Incommensuration Theorem in the essay on Bell's theorem, in Part II, and here I want only one aspect of the result.

The result is commonly called a paradox, because the result appears to violate locality, the principle that what happens at one place can be affected only by what reaches that place from nearby. In the experiments, the measurement at one system seems to settle something at the other system, across a separation that no signal can cross. Within the framework the result is not a paradox. The result shows a property of the domain that I call domain curvature. Domain curvature is the structural non-flatness by which no domain can be fully characterized in local terms. The two systems do not communicate. The two systems share a structural feature, a feature that belongs to the context in which the two systems were created together. The shared feature does not travel between the two systems, because the shared feature was never located in either system. The shared feature belongs to the domain, and the domain is curved.

By curvature I mean a property of a domain as such, in a sense of my own, and I do not mean the curvature of spacetime by which physics describes gravitation. When everything about a domain can be specified by specifying what is at each point, I call the domain flat. Some domains have features that no point-by-point specification captures: features that are properties of the relations among points and not of the points. I call a domain with such features curved. I argued in the essay on causation and connectivity that space is the connectivity topology of causal relations, and that the lightcone is primary. If space is the connectivity topology of causal relations, then the domain is a structure of relations before the domain is a set of places, and a structure of relations may carry features that are not localized anywhere. Entanglement is a feature of that kind. The

correlations that entanglement produces exceed what local causality can account for, because local causality is the flat approximation to a domain that is not flat.

The reading of entanglement as domain curvature fits the two boundaries. The macroscopic limit means that no signal can cross the separation between the two systems, and entanglement sends no signal: the statistics at one end cannot be steered from the other end. The microscopic limit means that no content can be specified finer than the grain of the domain, and entanglement specifies no content. Each outcome, taken alone, is as random as anything at the microscopic edge must be, in the terms of the framework. What the two systems share is context, and context is not carried by content. On this reading nonlocality is a direct expression of a structural principle, and not a mysterious feature to be explained away. The principle is that no finite domain is flat, and that the curvature of a domain shows itself as correlation beyond what any local account contains. I mark what I say about nonlocality in this section as a reading, at the depth that I call interpretation in this book. The reading adds nothing to the formalism of quantum mechanics, its mathematics, and the reading changes no prediction. The reading says why the formalism has the shape it has.

VIII. The Black Hole

The two physical horizons appear together in one object, the black hole. I end the substantive part of this essay with the black hole. The reason is that the black hole is the one place in this essay where I draw from the framework a claim that goes beyond a reading of a known result.

I described the microscopic boundary in terms of an event horizon in Section III, in the passage from Planck's constant to the Planck scale. The region one tries to measure closes on itself when the energy needed to measure the region is enough to curve space around the region. So physics itself describes the smallest scale of the domain in the language of the

largest scale. In a black hole the macroscopic horizon and the microscopic limit appear together. The macroscopic horizon appears as the event horizon, the one-way surface. The microscopic limit appears as the singularity, the point at which space and time cease to apply.

Consider what the event horizon and the singularity each are, in the terms of the Incommensuration Theorem. The theorem, stated in the Introduction, forbids two absolute conjunctions: symmetry with continuity, and asymmetry with discontinuity. The second forbidden conjunction, asymmetry with discontinuity, is the one that matters for the black hole. A perfect one-way interaction would be a sharp wall that lets things pass in one direction and never in the other, with nothing crossing back at all. A perfect one-way wall of that kind would be perfect asymmetry conjoined with perfect discontinuity. The theorem says that there is no such perfect one-way wall.

The event horizon of a black hole, as general relativity describes the event horizon, is not that wall. The event horizon is one-way by the smooth tipping of every cone. Where the arena differs enough from place to place, the cone of every event tips inward, and the asymmetry shows as a one-way boundary (*Measurement*, Chapter 5). A falling body encounters nothing local at the event horizon: the geometry is smooth across the horizon, and the one-wayness of the horizon is a property of the causal structure as a whole. So the event horizon is continuity with asymmetry carried as far as continuity with asymmetry goes, and the theorem permits that conjunction. A black hole gives off radiation, and the radiation arises at the horizon and outside the horizon. In the calculation by which physicists found the radiation, no signal sent from inside the horizon reaches the outside, so the horizon stays one-way as a boundary of the arena (*Measurement*, Chapter 13).

The singularity at the center of a black hole, as general relativity describes the singularity, is another matter. The singularity is a point at which the quantities of the theory become infinite, a perfect discontinuity, and the singularity is also a point toward which everything falls and from which nothing rises, a perfect asymmetry. So the singularity is an instance

of the forbidden conjunction. The framework is structurally more general than general relativity, in this sense: general relativity is one of the two survivors of the theorem (the two conjunctions that the theorem permits), applied to one domain, while the theorem applies to comparison as such. Therefore, on the framework, I expect that the singularity is an idealization that physics will not find physically realized as described. At the singularity the smooth description of general relativity comes to the edge of the domain of that description. To ask for the geometry at the singularity applies the concept of a smooth geometry where the concept does not belong (*Measurement*, Chapter 8). A perfectly discontinuous and perfectly asymmetric point is structurally incoherent, by the same argument that makes nothingness incoherent. I point to that argument in this volume, in the essay on the deep why. I develop the argument in the companion volume *Third Resolutions in Western Philosophy*. Physicists give the singularity, a point where the quantities of the theory become infinite, as one of the standing reasons for wanting a theory that general relativity alone does not supply. The claim about the singularity is therefore an exclusion rather than a reading, because the claim rests on the theorem, which forbids the conjunction that the singularity would be.

Two questions are left for physics. The first question is what replaces the singularity. The second question is what a black hole is when a theory that honors both survivors of the theorem describes the black hole, in the way the essay on cross-modal reach describes. A theory honors both survivors when the theory contains each survivor without perfecting both at once. The framework shows what the structural problem is. The framework contains no solution to the structural problem, and the solution is beyond the scope of the framework.

IX. Summary

Three of the claims that I make in this essay are claims at the depth of the metaphysics itself. The three claims are the claim about the three classes of knowledge (the known, the unknown and the unknowable), the claim that the three horizons are classes rather than instances, and the claim of the Law of Three. The reading of the speed of light and Planck's constant as the two boundaries of the domain of comparison, and the reading of entanglement as domain curvature, are readings of known results. One claim is a structural exclusion: the claim that a point singularity, perfect asymmetry with perfect discontinuity, cannot be physically realized as described. In this essay I mark where the unknowable begins, and I do not enter the unknowable.

There are three horizons. At the largest scale the horizon is the speed of light, beyond which nothing arrives. At the smallest scale the horizon is the limit that Planck's constant marks, below which nothing is distinguished jointly. At the scale of the self the horizon is the surface of unconsciousness, past which the self does not see. Each horizon recedes as it is approached. Each horizon is temporary as an instance and permanent as a class. Each horizon is the place where the unknown gives way to the unknowable. There are three horizons because there are three modalities and the unknowable appears in each modality.

The two physical horizons are the two constants that bound the domain of comparison, one constant a limit from the outside and the other a limit everywhere within, and between the two constants lies everything that can be measured. At the outer horizon the theorem says to expect asymmetry, and physics finds the lightcone. At the inner horizon the theorem says to expect discontinuity, and physics finds the quantum. Where the two horizons appear together, in the black hole, physics has described two things: a one-way surface, smooth and permitted, and a perfect point of discontinuity, which the theorem says cannot be as described.

The unknowable is the condition under which knowledge has a direction, and the unknowable is not the enemy of knowledge. The boundaries are horizons to be approached and not walls to be torn down. As a knower approaches a horizon, the knower's knowledge deepens. Without the horizon the journey of knowing would have no shape, because the journey would have nothing to move toward. The framework does not remove the horizon. The framework says where the horizon is, why the horizon is there, and that the horizon will always be there, and the framework says that the permanence of the horizon is not a defeat.

KEY CONCEPTS IN THIS ESSAY

- **The unknowable**: that which cannot be known even in principle, by any observer or method; distinct from the unknown, which is the not-yet-known; transcendent in modality.
- **Horizon**: a boundary that recedes as it is approached. A horizon is temporary as any instance and permanent as a class. A horizon is the place where the unknown gives way to the unknowable.
- **The macroscopic horizon**: the limit marked by the speed of light. The macroscopic horizon is the omniscient boundary of the domain, a limit from the outside, on the side of context.
- **The microscopic horizon**: the limit marked by the Planck constant. The microscopic horizon is the transcendent boundary of the domain, a limit everywhere within, on the side of content.
- **The surface of unconsciousness**: the subjective, mesoscopic horizon; the point past which the self cannot see itself; a class, not a fixed region.
- **Planck's constant and the Planck scale**: Planck's constant marks the microscopic limit, a bound on joint knowledge relative to energy. The Planck scale is built from Planck's constant, the speed of light and Newton's constant. The Planck scale is where a body's gravitational size equals the body's quantum size, and the Planck length is no least length.

- **Class and instance**: the absolute boundary of the knowable is defined in terms of classes. The relative boundary that an observer comes up against is an instance. Instances are crossed, and the class is not.
- **Law of Three**: a relation is always a relation of at least three. As a triplication theorem, the Law of Three says that for every way something is subjective there are two ways the thing is objective, and conversely. Three is the smallest number of mutually irreducible elements satisfying the intrinsics.
- **Domain curvature**: in a sense of this essay's own, and not the curvature of spacetime, the structural non-flatness of any domain, such that not everything about the domain is captured by specifying each point. Entanglement correlations are read as the expression of domain curvature.
- **The black-hole exclusion**: the singularity, as described by general relativity, conjoins perfect asymmetry with perfect discontinuity, which the Incommensuration Theorem forbids, so on the framework I expect the singularity to be an idealization. The event horizon is one-way by the smooth tipping of every cone: the event horizon is continuity with asymmetry, which the theorem permits.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorism 1.3-1 (the three axioms); aphorisms 1.89-1 through 1.89-3 (domain constants); the sections "The Known, the Unknown, and the Unknowable," "The Great Mystery," and "Triplication"; the Technical Appendix, "The Incommensuration Theorem."

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapter "The Limits of the Epistemic Process."

Landry, Forrest. *Third Resolutions in Western Philosophy.* Wytheville, Virginia: UVSM Publications. The treatment of why there is something rather than nothing.

Einstein, Albert, Boris Podolsky, and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47, no. 10 (1935): 777–780.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

Kennard, Earle H. "Zur Quantenmechanik einfacher Bewegungstypen." *Zeitschrift für Physik* 44 (1927): 326–352.

Hawking, Stephen W. "Particle Creation by Black Holes." *Communications in Mathematical Physics* 43 (1975): 199–220.

Riess, Adam G., et al. "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant." *The Astronomical Journal* 116, no. 3 (1998): 1009–1038.

Perlmutter, Saul, et al. "Measurements of Ω and Λ from 42 High-Redshift Supernovae." *The Astrophysical Journal* 517, no. 2 (1999): 565–586.

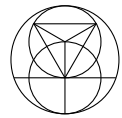
Abdo, A. A., et al. "A Limit on the Variation of the Speed of Light Arising from Quantum Gravity Effects." *Nature* 462 (2009): 331–334.

ATLAS Collaboration. "Evidence for Light-by-Light Scattering in Heavy-Ion Collisions with the ATLAS Detector at the LHC." *Nature Physics* 13 (2017): 852–858.

ATLAS Collaboration. "Observation of Light-by-Light Scattering in Ultraperipheral Pb+Pb Collisions with the ATLAS Detector." *Physical Review Letters* 123 (2019): 052001.

Landry, Forrest. *Comparison; The Necessary Basis.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-062-6. Chapter 9 (the Law of Three); Chapter 11, Section V (the Great Mystery).

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapters 5, 7, 8 and 13.



Essay 15

Domain Constants and the Span of Objectivity

Every Domain Is Bounded by Two Constants,
and the Span Between Them Is Its Degree of Structure

ABSTRACT

This essay follows the essay on the three horizons. In the essay on the three horizons I placed the speed of light and Planck's constant as the two physical horizons of the knowable. In this essay I generalize the two horizons from physics to every domain. A domain is the whole of what can be compared by one kind of comparison. Every domain, physical or otherwise, is bounded by two constants. One constant is a macroscopic limit on the side of context, the frame within which things are compared, and the speed of light is the physical instance of the macroscopic limit. The other constant is a microscopic limit on the side of content, what is compared within the frame, and the Planck constant is the physical instance of the microscopic limit. Between the two limits lies a mesoscopic scale, at which measurement has its natural meaning. The microscopic, mesoscopic and macroscopic scales correspond to the three things that every numerical measurement requires: a zero, a unit and an extent. Counted in orders of magnitude, the span between the two constants is the total degree of structuralization of the domain: the number of times content can be nested within context between the two limits. The span is also the bandwidth of the channel between self and world, and in Section IV I argue that the span is therefore the degree of objectivity that the do-

main admits. I then develop three correspondences, and all three correspondences share one pattern of three. The first correspondence is mass, energy and light, a triple in which interaction is more fundamental than substance or potentiality. The second correspondence is interaction, existence and creation, each of which has a zero and no maximum. The third correspondence is three equation types, equality, summation and product, of which summation appears at the macroscopic limit and product at the microscopic limit. This essay is the purest statement in this book of the metaphysics itself. In this essay I present correspondences. The numbers of the two constants express units, so there is no value of either constant to derive.

Note on framework. This essay depends on three earlier parts of this volume. I take four things from the Introduction to this volume: the six intrinsics, the Incommensuration Theorem, the three axioms and the modal alignment. I take one thing from the essay on the six measures and the six intrinsics, in Part I. In the essay on the six measures I divide the six measures into content measures and context measures. I also build on the essay on the three horizons, which immediately precedes this essay. Two chapters of my other books state principles that this essay uses. In the chapter on zero-positivity in *Unlocking Reality* I state the principle that every measure has a zero and no maximum. In the chapter on the nature of objectivity, in *Accessing the Real*, I state the account of objectivity as a degree. I build on both chapters here, and I do not restate either chapter. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. What a Domain Is

I have used the word ‘domain’ throughout this book, and here I define the word ‘domain’.

The essence of an act of measurement constitutes a domain: what a kind of measurement is, by its nature, makes up a domain. A reader might take a domain to be a region of space, a collection of objects or a set of laws. A domain is none of the three. A domain is the totality of what can be compared by a given kind of comparison. A content is what is compared, and a context is the frame within which the content is compared. So a domain has two ranges: the range of contents that a given kind of interaction can bring into relation with one another, and the range of contexts within which that kind of interaction can occur. Wherever there is measurement there is a domain, and the domain is whatever the measurement can reach, that is, whatever that kind of measurement can measure.

On this account the concept of "this universe," as people commonly use the phrase, is an instance of a domain. This universe is the domain of physical measurement: the totality of what can be compared by physical interaction. Is this universe the only domain of its kind, a special domain, or one domain among many? The concept of a domain says nothing about the answer, and the argument of this essay does not need to settle the question. What matters here is that the structure I describe in this book applies to any domain whatever: physical, mathematical, experiential or imaginal. Each domain has a kind of comparison proper to it. So each domain has the structure that belongs to comparison as such.

In this essay I am concerned with one part of the structure of comparison, the limits of a domain. In the essay on the three horizons I argued that the knowable has horizons, and that in physics two of the horizons are objective. In this essay I claim three things: every domain has two limits, the two limits are of different kinds, and the distance between the two limits is the single most important structural fact about the domain.

II. The Two Constants

The Planck constant and the speed of light are fundamental measures of the physical domain, in the sense that the two constants define its limits: the Planck constant defines the microscopic limit of the physical domain, and the speed of light defines the macroscopic limit. The two constants define the limits of what can be known as a part of the domain from a perspective within the domain, that is, the limits of what lies within the context of the domain as the content of the domain. Each constant divides what is actually known and potentially knowable from what is ultimately and irreducibly unknowable. But the two constants draw the division on different sides: the speed of light on the side of context, and the Planck constant on the side of content, and the difference between the two sides is the main thing to see in this section.

The historical system of units was built outward from the omniscient modality. The omniscient is the mode of structure: the structural, the measurable and the knowable. Length, mass and time were the original mechanical base units. Physicists established the three base units first, and later, through statistical mechanics and quantum mechanics, physicists took into physics the transcendent column of the six measures, probability and possibility. The transcendent is the mode of the generative and the potential, and the transcendent column is the column of the grid of the six measures that belongs to the transcendent. The International System of Units (the SI) was revised in 2019. The revised SI keeps the shape of the historical system. In the revised SI the kilogram is defined through the Planck constant h, so the new information that h carries goes into the definition of the kilogram. The Boltzmann constant k serves in the revised SI as a conversion between joules and kelvins. The transcendent measures themselves, probability and possibility, have no unit. The units were fixed in the order of their discovery. So the SI does not show that h and k are the two constants of the transcendent column. The hiding of h and k is an in-

stance of a broader pattern that I identify in the Immanent Metaphysics. Description proceeds from the omniscient modality. A description built from the omniscient modality tends to show both the immanent and the transcendent as subsidiary to the omniscient.

The SI divides the physical dimensions one way, and the reading by the intrinsics divides the physical dimensions another way. The relationship between the two divisions is analogous to a change of basis in linear algebra. A change of basis describes one space of vectors with a different set of basis vectors, the directions taken as coordinate axes, and the space itself does not change. Consider the vector space of dimensional specification, with the base kinds counted as the SI counts them. Leave out the mole and the candela, which are conventions layered on top of the others (the essay on the six measures, Section II), and give electric current and temperature each a base unit of its own. Counted in the SI's way, less the mole and the candela, the vector space has a fixed rank, the number of independent directions in the space. Counted instead as independent kinds of magnitude, the same space has the three kinds of mechanics, because the units of current or charge and of temperature add no kind of magnitude beyond mass, length and time. The SI and the reading by the intrinsics use different basis vectors for the same space. The SI uses as base kinds the dimensions of time, length, mass, current and temperature. The reading by the intrinsics uses the dimensions of the cesium frequency, the speed of light c, h (an action), the elementary charge e (a charge) and k (an entropy), so that in the reading by the intrinsics mass, current and temperature become derived. Counted with a base unit for each base kind, the rank is five in both bases. The total information content is the specification of all dimensionless ratios. The total information content is invariant under the change of basis. The two bases differ only in which directions are treated as the coordinate axes. In the Immanent Metaphysics I claim that the basis by the intrinsics is the basis that aligns with the six intrinsics of comparison, and therefore that in the basis by the intrinsics the modal structure is visible, where in the basis of the SI part of the modal structure is hidden.

The SI unit system is a historically evolved encoding of the relationships between physical dimensions. The SI is built in the order of discovery: mechanics first (length, mass, time), electromagnetism second (charge), thermodynamics third (temperature), and quantum mechanics last (absorbed into mass through h). The Immanent Metaphysics says that the order of discovery is not the order of nature.

The speed of light defines what is unknowable in terms of context. Time and space are context measures, as I set out in the essay on the six measures in Part I: time and space are the where and the when within which any content is found. The speed of light is a boundary between the times and spaces knowable from here, where the observer is, and the times and spaces intrinsically unknowable from here. The speed of light is the macroscopic limit. In the modal alignment that I hold fixed throughout this volume, the speed of light is the omniscient boundary of the domain: the outer edge of the shareable, repeatable pattern of connection.

The Planck constant defines what is unknowable in terms of content. Mass and force and probability are content measures, the what that is found within a context. Mass, force and probability are the static and dynamic aspects of pattern. The Planck constant is a boundary between the dynamics that are knowable and the dynamics that are intrinsically unknowable. The Planck constant is the microscopic limit. In the modal alignment of this volume, the Planck constant is the transcendent boundary of the domain: the finest grain of the possible, below which no further distinction is made.

When I mean the two constants as the boundaries of any domain, I call the two constants the C constant and the H constant. The C constant is the macroscopic limit of a domain, and the H constant is the microscopic limit. When I mean the physical instances, I call the two constants the speed of light and the Planck constant. I keep the two pairs of names apart because the claim of this essay is a claim about the whole class of domains, and not only about the physical domain.

The Incommensuration Theorem says what one finds at each of the two limits. The theorem is about four compounds of the six intrinsics: continuity, discontinuity, symmetry and asymmetry. When any two of the four compounds are applied absolutely and together, two conjunctions are forbidden: symmetry with continuity, and asymmetry with discontinuity. Two conjunctions survive: continuity with asymmetry, and symmetry with discontinuity. At the macroscopic limit one asks the context measures to extend without a gap, which is to ask for continuity absolutely. Where continuity is asked for absolutely, what one finds is asymmetry. The context measures are continuous at the macroscopic limit, and the light cone opens one way (the light cone of an event is the region of events that a signal from the event can reach). At the microscopic limit one asks the content measures to be perfectly repeatable, which is to ask for symmetry absolutely. Where symmetry is asked for absolutely, what one finds is discontinuity. The content measures are quantized at the microscopic limit, and the outcome of a measurement there cannot be refined. I develop the two findings from *An Immanent Metaphysics* in the essay on the six measures, and here I take that development as read. So the two constants are two different kinds of limit, and not two examples of one kind of limit. The C constant marks the place where the context, which is continuous, is found to be asymmetric. The H constant marks the place where the content, which is symmetric, is found to be discontinuous. The two constants are the physical faces of the two survivors of the theorem: the forms in which the two survivors appear in physics, and there are two constants because there are two survivors.

> **On the Generality of Domain Constants**
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> The two domain constants are intrinsic to all domains. Every domain has some representation of the two constants, in some manner or other: a coarsest reach, beyond which the domain's kind of comparison does not extend, and a finest grain, below which nothing can be told apart by the domain's kind of comparison. But each domain has its own values for the two constants, particular to that domain. A mathematical domain has a

> largest structure that can be named and a smallest difference that can be told apart. An experiential domain has a horizon of attention, the farthest that attention extends, and a threshold of discrimination, the smallest difference that a person can notice. The physical values are the values of the physical domain, and nowhere in this framework do I say what the physical values are. In this framework I say only three things about the values. There must be two constants, the two must be of the two kinds just named, a reach and a grain, and a domain lacking either constant would be a domain in which comparison had no edge. Under the Incommensuration Theorem, a domain in which comparison has no edge cannot exist.

III. Zero, Unit, and Extent: The Three Scales

Between the two constants lies a third scale, the mesoscopic scale. In *An Immanent Metaphysics* I describe the structure of the three scales together through three concepts that every numerical measurement requires.

All numerical measurement involves three concepts: a zero, a unit and an extent. The zero is the point below which the measure has no definite meaning. The unit is the reference against which other measures are compared. The extent is the reach beyond which the measure loses its structural character. Past the extent, the measure passes out of the domain's capacity to distinguish further. I develop three points in my chapter on zero-positivity in *Unlocking Reality*. Every fundamental measure has a zero and no maximum, and negative numbers refer to direction rather than to measure. Light is the clearest illustration of the principle of a zero and no maximum, because there is a limit to how dark a space can be but no limit to how bright. I take the principle of zero-positivity as established in *Unlocking Reality*. In this essay I use the principle of zero-positivity for what the principle says about the scales of a domain.

The zero corresponds to the microscopic boundary. The zero has the nature of the transcendent: the zero marks the point below which potentiality exceeds actuality and definite specification fails. In physics the zero is the limit that Planck's constant marks. In perception the zero is the threshold below which distinctions cannot be made: the faintest sound, the smallest visible difference, the point at which two stimuli are one.

The unit corresponds to the mesoscopic scale. The unit has the nature of the immanent, the mode of process. The unit is the relational ground, the comparison itself, the act of measuring. In physics the mesoscopic scale is the human scale, the scale of the laboratory and the instrument, and at the human scale a meter and a second are what they are. In perception the mesoscopic scale is the scale of ordinary experience, where things have their natural sizes.

The extent corresponds to the macroscopic boundary. The extent has the nature of the omniscient: the extent marks the structural horizon beyond which the description of the domain ceases to apply. In physics the extent is the cosmological horizon, the surface from which nothing has yet arrived. In perception the extent is the limit of causal contact, the farthest thing by which one can be affected.

So each domain has three scales, and the three scales are the three modalities. The microscopic scale is transcendent, the mesoscopic scale is immanent, and the macroscopic scale is omniscient, and the whole volume uses this alignment of the three scales with the three modalities. The zero, the unit and the extent show the alignment of the whole volume from the side of measurement. In the alignment of this volume, the transcendent domain is where quantum mechanics is applied, the omniscient domain is where general relativity is applied, and the immanent scale between the two domains is where the measuring is actually done.

In this essay I extend the word "projection" to the other two scales of the domain, the mesoscopic scale and the macroscopic scale. At the microscopic limit the word has a definite sense. In *The Story of the Particles* (Level 6) I find the six intrinsics of comparison re-projected, at the micro-

scopic limit, as the kinds of constituent, and I call that finding re-projection. When I extend the word to the other two scales, I make an identification in this book. At the mesoscopic and macroscopic scales I claim that what is found at each scale is shaped by the modal character of the scale, and I do not claim that the kinds found at the mesoscopic and macroscopic scales are the intrinsics. The shape at each scale comes later in this section.

The three scales of projection are themselves a triple: the microscopic, the mesoscopic and the macroscopic. The three scales satisfy the three conditions that Axiom III sets for a triple: the three members are distinct, inseparable and non-interchangeable.

Distinct. The three scales are different from one another. At the microscopic scale, projection produces discrete, quantized, particle-like entities. At the macroscopic scale, projection produces continuous, extended, cosmological structure. At the mesoscopic scale, projection produces the familiar dynamics of forces and motions. So the three scales are not three names for the same thing.

Inseparable. No scale exists without the other two. The microscopic has meaning only in contrast with the macroscopic. The concept of "very small" requires a "very large" against which the very small is measured. The mesoscopic is the scale at which the contrast between the very small and the very large is drawn: the scale from which both the microscopic and the macroscopic are defined as limits. Without all three scales, the concept of scale itself is empty.

Non-interchangeable. The three scales cannot be substituted for one another. Quantum mechanics cannot do the work of general relativity: quantum mechanics is the theory applied at the microscopic scale, and general relativity is the theory applied at the macroscopic scale. Classical mechanics cannot replace quantum mechanics, and classical mechanics is the mechanics of forces and motions at the mesoscopic scale. Each scale has a structural role that the other two scales cannot fulfill.

Things found by comparison have a different form at each scale, because each limit has a different character. At the mesoscopic scale, comparison is performed. No constant of physics bounds the mesoscopic scale. The limit of the mesoscopic scale is the act of comparing, which is never the content of any comparison. What appears at the mesoscopic scale is the six measures of measurement, as the frame in which mechanics is written. The six measures appear in three pairs: mass in space, force in time, and probability in possibility. The three pairs are the three modal columns of the grid of the six measures (*Comparison; The Necessary Basis*, Chapter 8; the essay on the six measures, Section III). The three axioms state how the three columns are related. The six intrinsics as kinds do not appear at the mesoscopic scale, because the six intrinsics as kinds belong to the finest grain.

On the Grain of Projection

The progression from microscopic to macroscopic is a progression in the grain of what is found. At the finest grain, the microscopic limit, what is found is the six intrinsics, re-projected as kinds. At the middle grain, the mesoscopic scale, what is found is the three modal columns of the six measures, together with the axioms that state how the three columns are related. At the coarsest grain, the boundary of the C constant, what is found is the triple concept itself, into which the concept "universe" resolves: existence, interaction and creation (*Incommensuration*, Chapter 9, Section I; Section VI of this essay). The progression is an identification that I make in this book. The identification depends on two things that this book says of the two physical limits, in the essay on the six measures, Section V, and in the essay on the three horizons, Section VI. Content must be quantized at the absolute microscopic scale of a domain, so the microscopic limit is where content is articulated into separate kinds. Context must be continuous at the absolute macroscopic scale, so the macroscopic limit is where only the broadest structural feature appears.

On the Axiom II Rotation

In *An Immanent Metaphysics* I also describe the three concepts of measurement (zero, unit and extent) as position, scale and direction. Position is where a thing is in the ordering, and position is omniscient. Scale is the transformation between levels, and scale is transcendent. Direction is the flow from toward to away, and direction is immanent. The modal assignments of position, scale and direction are shifted by one place relative to the modal assignments of zero, unit and extent. The shift is an Axiom II rotation, and not an error. An Axiom II rotation is a rotation of the bindings, the assignments of concepts to modalities, between two contexts of consideration. The rotation follows the order of the cycle of the second axiom, in which a class of one modality precedes an instance of the next modality: omniscient to transcendent to immanent to omniscient. The rotation is a concept in addition to the second axiom, and not a restatement of the second axiom (*Incommensuration*). When the context of consideration moves from the structure being measured to the act of measuring, the modal assignments rotate by one step. When the same concepts are considered in different contexts, the modal associations of the concepts are shifted, and the shift is a change of perspective rather than a change of doctrine. I note the rotation here because the rotation recurs in Section VII, on the three equation types.

IV. The Span as the Degree of Structuralization

The central claim of this essay is about the span of a domain.

For an observer within a domain, the degree of objectivity that the domain admits is proportional to the span of the domain: the distance, in orders of magnitude (factors of ten), between the macroscopic limit and the microscopic limit of the domain. The larger the span, the richer the domain, the more structure the domain admits, and the greater the bandwidth of the channel between self and world within the domain.

I will give the reason in the terms of this framework, beginning with what objectivity is. Objectivity is a degree and not a state, as I argue in my chapter on the nature of objectivity in *Accessing the Real*. Nothing is purely objective. Objectivity is a property of clusters of related perceptions, and not a property of any single perception. The degree of objectivity is the product of three factors. The first factor is the intensity of the interaction between self and world. The second factor is the macroscopic consistency of the interaction across contexts: the symmetry component, sameness of content across difference of context. The third factor is the microscopic potentiality within the interaction: the genuine novelty that no prior state of the observer could have predicted, and the randomness without which a perception carries no information from outside the self. The third factor is missing from most accounts of objectivity.

Now set the three factors of objectivity beside the two constants of the domain. Consistency is established across contexts, and the range of available contexts is bounded above by the macroscopic limit: the farther the reach of the domain, the more contexts there are across which a pattern can be found the same. Potentiality occurs at the finest grain, and the finest grain is bounded below by the microscopic limit: the smaller the grain, the more room there is for what is new to occur below the threshold of prior specification. So the span between the two limits is the range of scales at which consistent perceptions and informative perceptions are both possible. A domain with a wide span admits many levels of organization, many degrees of objectivity and many scales of interaction, and each level can serve as content for the level above and as context for the level below. A domain with a narrow span admits little structure and little objectivity: there is almost no room between the point at which consistency breaks down and the point at which information disappears.

I call the count of how many times content can be nested within context, between the grain and the reach of a domain, the total degree of structuralization of the domain. The count of nesting is also why I describe the span as the bandwidth of a communication channel between self and world. The bandwidth of a channel is how much the channel can

carry, and the channel between self and world carries as much as the number of distinguishable levels between its floor, the microscopic limit, and its ceiling, the macroscopic limit.

For the physical domain the span is very large. The Planck length is the length formed from Planck's constant, the speed of light and Newton's constant of gravitation. The Planck length is about 1.6 times ten to the minus thirty-five meters, the radius of the observable universe is about 4.4 times ten to the twenty-six meters, and the two lengths are about sixty-one orders of magnitude apart. I quote the figures descriptively, as facts about the physics, and not as results of this framework. The span is a ratio of two lengths. The lower end of the span is the scale at which the description of context and the description of content meet, and the lower end of the span is not a least length, a smallest possible piece of space. In this framework I say only one thing about the span: a span of that size is why physics is capable of objectivity of such high confidence. A span of that size holds very many levels, at which pattern can be found consistent and novelty can still occur. The sciences are arranged along the levels, from the nuclear through the atomic, the molecular, the biological, the planetary and the stellar to the galactic, and each level is a layer of structure made possible by the room between the two constants. If the span of a domain were a few orders of magnitude, the domain would have no ladder of levels like the ladder of the sciences, and no objectivity of such confidence.

The proportionality between objectivity and span is a structural correspondence: the degree of objectivity rises with the span, for the reason given in this section, which is that consistency needs a wide reach and novelty needs a fine grain.

V. Mass, Energy, and Light

The two constants have a companion triple among the fundamental concepts of physics, mass, energy and light, and the triple follows the modal pattern of the three scales: one member is omniscient, one is transcendent and one is immanent.

Three concepts have the nature of the omniscient: the concept of a state, of a structure and of a configuration. The concept of matter has the nature of the omniscient too, and so, ultimately, does the concept of mass itself. Mass is pattern. Mass is the fixed, structural, repeatable aspect of a domain: the thing that stays the same and can be counted on to stay the same.

In the re-ordered system of units described in Section II, the basis by the intrinsics, mass is a derived quantity. Mass is not a base quantity introduced by h. Mass is fixed by the constants already introduced, together with a characteristic spatial scale: the grain of possibility (h), the bridge between space and time (c, the constant that relates a distance to a time), and a length λ. The Compton wavelength of a body of mass m is defined by $\lambda = h/(mc)$, so $m = h/(c{\cdot}\lambda)$. So mass is the ratio of the grain of possibility to the product of c and a length in space. Mass is derived from what precedes mass in the chain of steps from comparison to physics: possibility (through h), space (through λ), and the bridge between space and time (through c) (*Measurement; The Steps from Comparison to Physics*, Chapter 7, Section II).

> **On the Compton Relation**
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> The equation $m = h/(c{\cdot}\lambda)$ can be rearranged as $m{\cdot}c{\cdot}\lambda = h$. The left side is mass (pattern, the omniscient content) × the speed of light (the bridge between space and time) × a spatial extent (space, the omniscient context). The right side is Planck's constant (the grain of possibility, in the transcendent column). The relation is the definition of the Compton

wavelength. In the reading of the chain of steps from comparison to physics, the relation shows how a mass is fixed once h, c and a length are given: the omniscient specification of a particle (the mass of the particle and a spatial extent), joined through c, equals the grain of possibility. The relation is not an instance of the form I = O × T (the essay on cross-modal reach, Section VIII), in which I, O and T stand for the immanent, the omniscient and the transcendent. The form I = O × T states the conjugate relationship of roles in Axiom I, and the form is not a multiplication of quantities. What the Compton relation does show is that, in the decomposition by the intrinsics, mass is not a base: mass is fixed by the grain of possibility, the bridge between space and time, and a length.

The concept of a relation between states has the nature of the transcendent, and so do the concept of a comparison of possibilities in terms of their probability and, ultimately, the concept of energy itself. Energy is potentiality. When one refers to a measure of energy, one refers to a difference of potential states: to what could happen rather than to what is.

The concept of measurement has the nature of the immanent, and so do the concepts of interaction, of the transformation of states, and of force, power and strength. Ultimately the concept of observation itself, which is light, has the nature of the immanent too. Light is interaction in the frame of the simplest physical comparison: two atoms and the light that passes between the two atoms. Light is the processual act by which pattern and potentiality are brought into relation. In the physical domain, light is the thing by which anything is seen at all. I use the word "light" in that widest sense, for the carrier of every measurement, and not for the visible band alone.

Each of the three axioms applies to the triple of mass, energy and light, and I apply each axiom in turn.

The first axiom says that the immanent is more fundamental than the omniscient and/or the transcendent. The first axiom also says that the omniscient and the transcendent are in conjugate relationship to one another, so that neither of the two can be eliminated in favor of the other. So inter-

action, which is light, is more fundamental than both matter and energy, and matter and energy are the omniscient face and the transcendent face of light, related to each other through light. I read the equivalence of mass and energy in two parts. First, mass and energy are one currency (*Measurement*, Chapter 7). Mass and energy are the two faces of a single interaction, held in proportion, and not traded one against the other. Second, the constant relating mass and energy is the constant that bounds interaction, which is the C constant. I mark the two parts as a reading, in the sense of the Introduction. In a reading, a known result of physics is taken as an instance of the structure of comparison. The reading says why the relation of mass and energy has the form it has, but the reading does not produce the relation.

By the third axiom, mass, energy and light are distinct, inseparable and non-interchangeable. All matter has some energy and some interactivity. All interactivity has some structure and some potentiality. All potentiality has some substance and some accessibility. Each of the three requires the other two, and none of the three is reducible to another.

The second axiom says that a class of one modality precedes an instance of the next modality, around the cycle from the omniscient to the transcendent to the immanent and back to the omniscient. A class is a kind taken as a whole, and an instance is one particular case of a kind. Applied to mass, energy and light, the second axiom gives three precedences. Before there is any slight degree of energy, of potentiality, there must be significant degrees of matter, because a class of the omniscient precedes an instance of the transcendent. Before there is any slight degree of light, of interaction, there must be significant degrees of energy, because a class of the transcendent precedes an instance of the immanent. Before there is any slight degree of matter, of actuality, there must be significant degrees of light, because a class of the immanent precedes an instance of the omniscient. So mass, energy and light precede one another in a cycle, and none of the three is first.

I add one further point about mass in particular: in this framework I take mass and pattern as equivalent. Mass and pattern are isomorphic by way of the principle that the physicist Ernst Mach proposed: the inertia of a thing, the thing-ness of a thing, is defined by the relationship of change of the thing to all other things. Consider the relationships of a thing to all other things, in terms of the changes of the relationships: the total structure of the relationships, so considered, is the being of the thing as pattern. It follows from the equivalence of mass and pattern, as a correspondence and not as a calculation, that mass is inversely proportional to the degree of potentiality of the interactions among interactions. The more confined and isolated an interaction is, the more dynamism and potentiality the interaction develops, and the smaller and more confined an interaction is, the more energy is required to perceive the interaction. The last clause states the content of the uncertainty relation, as I read the uncertainty relation in the essay on the three horizons: a content and its context cannot both be fixed beyond the bound that Planck's constant sets. The clause about energy and perception also marks the point at which the triple of mass, energy and light connects with the H constant. The finest grain of the domain is the scale at which the energy required to perceive a thing becomes the energy that destroys the thing perceived.

VI. Interaction, Existence, and Creation

Every fundamental measure has a zero and no maximum. The principle of zero-positivity has consequences beyond measurement, in ontology, the study of what exists. I list three of the consequences here, because the three consequences show why the two constants are the kind of constants they are.

Interaction is zero-positive: the degree of interaction has a zero and no maximum. Interaction is unavoidable: one always interacts. There is no anti-interaction, no negative degree of contact between self and world. The degree of interaction can be small and can approach its floor, but

there is no regime beneath the floor. The floor of interaction is why the microscopic limit is a limit. Below the H constant there is not less interaction but no distinguishable interaction, and the difference between less and none is the difference between a scale within the domain and the edge of the domain.

Existence is zero-positive. In this framework existence is structural permanence: the persistence of a pattern across contexts. There can be degrees of existence, but there is no negative existence, no thing whose degree of persistence is less than none. The floor of existence is why the macroscopic limit is a limit. Beyond the C constant there is not a region of lesser existence but a region about which the question of existence cannot be posed from here, because no pattern from that region persists into here.

Creation is zero-positive. Creative potentiality, the entry of the new, can be greater or lesser, but creative potentiality cannot be negative. There is no anti-creation, no removal of possibility that goes below the possible. The zero-positivity of creation is what makes the third factor of objectivity, novelty, a factor: the novelty that occurs at the finest grain has a floor of zero and no ceiling, and so an observer within the domain can always be surprised.

Creation is present wherever interaction and existence are present, because interaction, existence and creation are inseparable. The order among the modalities in the axioms is an order of precedence, and not an order of clock time. So under the axioms creation does not come at an earlier time than interaction, and creation is not confined to the past. Creation is an aspect of every event, and not an event of its own. My conclusion disagrees with every account that places creation at a first moment, and agrees with the traditions that hold creation to be continuous.

The implications of the conclusion for physics are direct. As physics is ordinarily practiced, physicists treat creation, existence and interaction as separate: creation comes first and then stops, existence follows as a standing condition, and interactions follow with no further newness. Creation

is ongoing and not historical, so the universe is not a system whose whole history is fixed by its initial conditions. Something new enters in every interaction, and the new thing makes a finding that is not contained in what came before. Genuine novelty is a structural feature of every moment.

The three consequences are once again a triple, in the modal alignment of this volume. Interaction is immanent, existence is omniscient and creation is transcendent. The three consequences also concern a further question: why there is something rather than nothing. I otherwise leave the question to the companion volumes of this book. The degree of interaction is always positive. The degree of interaction can never be zero in an absolute sense, because zero is the edge of the domain. Zero is not a state within the domain. So there is always at least the irreducible fact of contact between subject and world. In the terms of the framework, the irreducible fact of contact is why there is something rather than nothing. In the essay on the deep why, in Part II, I say why physics cannot pose the question. In the essay on the deep why I also point to where the question is taken up.

I confirm the triple of existence, interaction and creation by a test of exhaustiveness, a check that the triple leaves nothing out. Is there any content to the concept "universe" that is not captured by existence, interaction, and creation? Consider any candidate for a fourth aspect of the universe. Space is an aspect of existence (the structural extension of what is). Time is an aspect of interaction (the processual ordering of events). Possibility is an aspect of creation (the range of what could come into being). Law is an aspect of existence, because law is the regularity laid out as pattern, and the omniscient is the structural and the repeatable: existence, pattern and law are all omniscient (the essay on three kinds of acceleration, Section IV). Matter is an aspect of existence (the structural content of what is). Force is an aspect of interaction (forces unfolding across time). Energy is neither a fourth aspect nor an aspect of one of the three alone, because energy is a relation across the columns of all three modalities, expressible in the six measures. The energy of a configuration is a relation of pattern in space across possibility, and the energy of motion is expressed through momentum, force and time (*Measurement*, Chapter 7, Section I).

In the triple of mass, energy and light of Section V, energy is the transcendent face of light. The triple of Section V is a different triple from existence, interaction and creation, and bindings in two different triples do not conflict. Every candidate reduces to one of the three aspects, or to a relation among the three aspects. I have checked only the candidates named here. I make the claim of exhaustiveness itself in *Incommensuration* (Chapter 9, Section I), the claim that if one knew everything about existence, interaction and creation, nothing in the universe would be left out.

On the standard conception, the universe is a container. The container conception is the omniscient projection of the triple of existence, interaction and creation onto spatial and temporal extension. On the container conception, existence is the primary aspect. Interaction and creation are subsumed into the container as events and processes that occur within the container. I reverse the container conception. The universe is the triple of existence, interaction, and creation, and not a container within which things happen. The arena of space and time is the omniscient face of the triple: the face that admits of mapping, measurement, and structural description, but the arena of space and time is only one face of the triple. The immanent face is interaction: the ongoing, processual, relational ground of everything. Every measurement is an interaction. Every comparison is an interaction. The relational character of the universe is a feature of the being of the universe, and not a feature of its contents. The transcendent face is creation: the ever-present potential for the new, and not an event in the past. The transcendent cannot be contained in spatial or structural categories. The transcendent cannot be located, mapped, or fully described. The transcendent can only be recognized from the inside, through participation.

VII. The Three Equation Types

The last correspondence of this essay is the correspondence between the three modalities and three types of equation.

Consider a relation between two selves in a single common world, in terms of the total information that each self holds. I identify three equation types by which a relation between two selves can be expressed, one for each modality. In *Category Theory and the Immanent Metaphysics* I prove the assignment of the arithmetic operations to the modalities (Chapter 9). Addition is the act of joining two things into one, and addition is interaction. In a pure immanent modality the equation of information is a pure summation: what the one self holds and what the other self holds add to what is between the two selves, and the contributions of the two selves are separable. The result of a multiplication is the complete table of all pairs, a pattern given all at once. In a pure omniscient modality the equation of information is a pure product: the contributions are not separable, and the whole is the full table of the pairings of the contributions. The result of an exponentiation is the space of all possible functions, every way things could go. In a pure transcendent modality the equation of information has the form of a power, with its inverse, the logarithm. A class of additions produces a multiplication, and a class of multiplications produces an exponentiation, in the order of the second axiom.

Across the scales of a domain, the three equation types appear as follows. At the macroscopic limit, relations are expressed in terms of summation, equations of the form X plus Y equals zero, with a basis in symmetry. X plus Y equals zero is the form of a conservation law, in which what enters and what leaves sum to nothing. In the essay on the two types of law, in Part I, I argued that conservation is what symmetry requires of a domain. At the microscopic limit, relations are expressed in terms of product, equations of the form X times Y equals one, with a basis in continuity. X times Y equals one is the form of the uncertainty relation, in which two spreads multiply to a fixed quantity, and neither spread can be reduced without the other spread growing. In intermediate dimensionalities, the scales between the two limits, relations have the form of a power law or a logarithmic relation. Power-law and logarithmic relations produce constructions that repeat their structure across scales: the fractal forms of which the mesoscopic world is full.

One rule fixes where each equation type appears. Summation, which is immanent, appears at the macroscopic limit, which is omniscient. Product, which is omniscient, appears at the microscopic limit, which is transcendent. The power law and the logarithm are transcendent, and they appear at the scale between the two limits, which is immanent. So the modality of each equation type is one step along the cycle of the second axiom from the modality of the scale at which the equation type appears. The three steps are the three precedences of the second axiom: a class of the immanent precedes an instance of the omniscient, a class of the omniscient precedes an instance of the transcendent, and a class of the transcendent precedes an instance of the immanent. Conservation laws take summation form, and the uncertainty relation takes product form, and both are facts about the physics. I prove the modal characters of the arithmetic operations in *Category Theory and the Immanent Metaphysics*. A single step joins the facts about the physics to the proved modal characters of the operations: the step along the cycle of the second axiom.

VIII. Summary

Almost every claim in this essay is a claim of the metaphysics itself: what a domain is, that a domain has two limits of two kinds, the three scales, the triples, and the zero-positivity of the degrees of interaction, existence and creation. Three claims of this essay are readings of known results. In the first reading, the speed of light and Planck's constant are the physical instances of the two limits. In the second reading, mass and energy are one currency, related through light. In the third reading, conservation and uncertainty are summation and product at the two limits. Each reading states the structural reason that the known result has its form. In this essay I make no structural exclusion of my own, that is, no claim of what physicists will not find.

Every domain is bounded by two constants. One constant is the macroscopic limit of context, the omniscient edge beyond which no pattern arrives. The speed of light is the physical case of the macroscopic limit. The other constant is the microscopic limit of content, the transcendent edge below which no difference is made. The Planck constant is the physical case of the microscopic limit. Between the two constants lies the mesoscopic scale of the measuring self. The three scales are the zero, the unit and the extent of every measurement that the domain contains: the microscopic limit is the zero, the mesoscopic scale is the unit, and the macroscopic limit is the extent.

The span between the two constants is the degree of structuralization of the domain, the bandwidth of the channel between self and world, and the measure of the objectivity that the domain admits. The physical domain has a very wide span. The width of the span is why physicists can be as sure of their results as they are.

Mass, energy and light form a triple: mass is omniscient, energy is transcendent and light is immanent. In the triple, interaction is more fundamental than substance or potentiality. Interaction, existence and creation each have a zero and no maximum, and the zero-positivity of the three is why the edges of a domain are edges and why there is always something rather than nothing. And the relations at the two edges have two forms: summation at the reach, the macroscopic limit, and product at the grain, the microscopic limit. The modality of each of the two forms is one step along the cycle of the second axiom from the modality of the scale at which the form appears.

On this account, the structure of physics is a specific instance of the general structure that any domain must have. The structure of physics includes its equations, its constants and its fundamental concepts. The two domain constants are intrinsic to all domains. In physics, the numbers of the two constants express the units in which the physical domain is measured. The speed of light has been fixed by the definition of the meter since 1983, and Planck's constant by the definition of the kilogram since 2019, so

there is no fact about the values of the two constants to explain. The quantities measured in the physical domain are the dimensionless ratios, which the fixed values of the two constants leave untouched.

KEY CONCEPTS IN THIS ESSAY

- **Domain**: the totality of what a given kind of comparison can reach; constituted by the essence of an act of measurement; "this universe" is an instance.
- **C constant**: the macroscopic limit of a domain, on the side of context; the omniscient boundary; the speed of light is its physical instance.
- **H constant**: the microscopic limit of a domain, on the side of content; the transcendent boundary; the Planck constant is its physical instance.
- **Zero, unit, extent**: the three concepts every numerical measurement requires; microscopic and transcendent, mesoscopic and immanent, macroscopic and omniscient respectively.
- **Domain span**: the distance in orders of magnitude between the two constants; the total degree of structuralization of the domain and the bandwidth of the channel between self and world.
- **Objectivity as degree**: the product of intensity, consistency, and potentiality; proportional to the span; never absolute.
- **Mass, energy, light**: a triple; mass omniscient as pattern, energy transcendent as potentiality, light immanent as interaction; interaction more fundamental than either.
- **Zero-positive degrees**: interaction, existence, and creation each have an absolute minimum of zero and no maximum; negative values refer to direction, not measure.
- **Three equation types**: summation for the immanent, product for the omniscient, power and logarithm for the transcendent (*Category Theory and the Immanent Metaphysics*, Chapter 9); each appears one step along the cycle of the second axiom from its scale: summation at the macroscopic limit, product at the microscopic, power law between.

- **Axiom II rotation**: the rotation of modal bindings by one step when the context of consideration changes; it follows the order of the second axiom's cycle, and is a concept in addition to that axiom.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorism 1.3-1 (the three axioms); aphorisms 1.82-1 through 1.82-7 (zero-positive; zero, unit, extent; position, scale, direction; the phase shift); aphorisms 1.87-3 through 1.87-10 (mass and energy); aphorisms 1.89-1 through 1.89-3 (domain constants); aphorisms 1.75-20, 1.88-5, and 1.88-6.

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapters "Zero Positive" and "The Universal Law."

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapters "On the Nature of Objectivity" and on the six measures.

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

Mach, Ernst. *The Science of Mechanics: A Critical and Historical Account of Its Development.* Translated by Thomas J. McCormack. Chicago: Open Court, 1893.

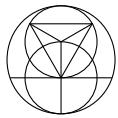
Landry, Forrest. *Comparison; The Necessary Basis.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-062-6. Chapter 8 (the six measures and the six intrinsics).

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3. Chapter 9, Section I (the concept "universe" as the triple of existence, interaction and creation).

Landry, Forrest. *The Story of the Particles.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-053-4. Level 6 (re-projection).

Landry, Forrest. *Category Theory and the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-071-8. Chapter 9 (the arithmetic modal triple).

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapter 7 (units, constants and the limits of a domain).



Essay 16

The Microscopic Boundary and Quantum Indeterminacy

Where Creation Enters a Domain,
and What Physics Finds There

ABSTRACT

In my book *Unlocking Reality* I give an account of creation: creation is real but does not exist, creation is an aspect of all events rather than an event, and creation has no source, no location and no measure. This essay develops the one part of that account which bears directly on physics: creation is not a process and has no position, yet creation enters a domain through the domain's microscopic boundary, the limit of the domain at the small end. Quantum indeterminacy is the fact that nothing within a domain fixes the outcome of a single quantum event, and quantum indeterminacy is the physical expression of creation's entrance through the microscopic boundary. I read the indeterminacy of a single quantum event as the way that potentiality arriving from the transcendent appears from inside the domain. Macroscopic order emerges from the aggregate of many quantum events. I read the emergence of macroscopic order as the form that the second axiom takes in physics. I then read the uncertainty relation of the physicist Werner Heisenberg as an instance of the Incommensuration Theorem, by three routes that agree. A trajectory is a path with every position and every momentum fixed at every instant. On the first route, a trajectory would perfect continuity and symmetry together. On the second route, the uncertainty relation pairs the two survivors of the

theorem and never the forbidden pair. The two survivors are continuity with asymmetry and symmetry with discontinuity. The forbidden pair is continuity with symmetry. On the third route, the form of the uncertainty relation is the conjugacy of the first axiom: the omniscient and the transcendent are in conjugate relationship. I say plainly that the size of the bound comes from physics and not from the metaphysics. I connect the strength of the creative aspect to clarity rather than to simplicity. The three mysteries are the three places where the knowable gives way to the unknowable. I describe where each of the three mysteries appears in physics. I close with the question of whether the laws of physics are created or discovered, and my answer is that the answer depends on where the boundary of the self is placed. The central claims are readings of known results.

Note on framework. This essay depends on the Introduction to this volume for four things: the six intrinsics, the Incommensuration Theorem, the three axioms, and the modal alignment. This essay also depends on the essay on hard randomness in Part II and on the essay on the three horizons, the essay just before this one. In the essay on the three horizons I establish the three mysteries, and I establish the two physical boundaries as classes: each boundary is permanent as a class, while each instance of the boundary is temporary. In my book *Unlocking Reality*, two chapters contain the general accounts on which I build in this essay. In the chapter on the theory of creation I give the general account of creation, and in the chapter on the known, the unknown, and the unknowable I give the general account of the three categories of knowledge. I build on the two chapters in this essay and do not restate the two chapters. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. Where Creation Enters

I established a series of negative characterizations of creation in the chapter of *Unlocking Reality* on the theory of creation. A negative characterization says what creation is not. Creation is not actual, because actuality is pattern and creation is potential. Creation is not observable, because observation yields content, and creation is the context from which content emerges. Creation is not conserved, because conservation is a law of symmetry, and creation is transcendent, on the side of continuity, which has the nature of the transcendent in the modal alignment of this book. Creation is not repeatable, because repetition is symmetric, and the transcendent is asymmetric. Creation has no source, because creation is cooperative across every boundary of self, every line between a self and what is not that self. And creation is an aspect of all events, rather than an event itself. I take all of these characterizations as established. I do not argue for the characterizations again in this essay.

In *An Immanent Metaphysics* I give one positive characterization of creation. The positive characterization concerns a scale that physics can study: the scale of the very small. Creation is not a process, but creation typically involves the microscopic boundary of a domain. Creative potentiality enters a domain through the scale of the very small. But creative potentiality enters at no particular position in time or space.

I want to be careful about what the positive characterization says, and what the characterization does not say. The characterization does not say that creation is located at the microscopic scale, because creation has no location. The characterization does not say that creation is a microscopic process, because creation is not a process. The characterization says three things. First, a domain has a boundary at the small end. Second, what is transcendent to the domain enters the domain across that boundary. Third, seen from inside the domain, the entering has the look of the very

small. So the microscopic boundary is the place where the transcendent enters the domain. The entering itself has no place: no position in time or space.

A picture from computing shows the source of the information in an event. Suppose a very small amount of information causes a great many things to happen, and what happens holds much more information than the cause did. Then we are dealing with an information world, a simulated world, in which a command can call down to the substrate of the system, the underlying machine that runs the simulation, and delete a file tree, or copy a file tree, or create a file tree. Compare the bits of information that go into the command with the bits of the changes of state that result. If I delete a terabyte of data with a single command, twelve bits go in and a terabyte comes out. In a computational universe there is no proportion between the number of input bits and the number of output bits. The asymmetry between the bits in and the bits out is arbitrary, because the command uses the causation of the substrate, the causation of the underlying world, as a direct way of making things happen. In the visible universe we are not dealing with a simulation, and there is no substrate below the world: there is one level only, physicality, and all of the phenomenal information, the information in what happens, must come from somewhere within that one level. Some of the phenomenal information comes from prior states, through causation. Some of the phenomenal information comes in through the microscopic boundary, as hard randomness, the residue of what happens that no prior state accounts for. To make one fireball in a simulation I need to say how much heat there is, where, and for how long. Some procedure has to create every bit of information in the fireball, and any bit that no procedure creates still has to come from somewhere. In a simulation, that information comes from the operating system, which already held all of the information and which the command draws on: the information comes from the substrate level.

Why does creation enter through the microscopic boundary and not through the macroscopic boundary? I aligned each of the two boundaries with a modality in the essay on the three horizons. The macroscopic limit

of a domain is the horizon marked by the speed of light. The macroscopic limit is the same thing as the macroscopic boundary. The macroscopic limit has the nature of the omniscient: the macroscopic limit is a limit from the outside, the edge of the structural description of the domain, beyond which the pattern of the domain no longer applies. The microscopic limit of a domain is the horizon marked by the Planck constant. The microscopic limit is the same thing as the microscopic boundary. The microscopic limit has the nature of the transcendent. The microscopic limit is a limit everywhere within the domain, the edge below which no definite specification is possible. Creation has the nature of the transcendent. What is transcendent enters a domain through the transcendent boundary of the domain. So the microscopic limit is the surface through which creation comes in, not a wall that keeps creation out, and the microscopic limit is everywhere, because the very small is everywhere.

II. Indeterminacy as the Physical Face of the Boundary

In *An Immanent Metaphysics* I state directly what follows for physics from creation entering through the microscopic boundary: quantum indeterminacy is the physical expression of the creative aspect of reality at the microscopic limit. A single quantum event shows minimal organization. Vast numbers of quantum events, taken together, show an emergent order. The emergent order makes up the macroscopic world. Creative potentiality enters through the microscopic and shows itself through the aggregate of many events.

I develop the physical consequence in three steps. The three steps are what indeterminacy is on my reading, why indeterminacy must look as it does from inside the domain, and how the aggregate of many events turns indeterminacy into order.

First, what is indeterminacy? In the essay on hard randomness, in Part II, I argued that there is a residue in what happens which no prior state accounts for. There is nothing prior from which the residue follows, and

so no prior state accounts for the residue. The reason is not that the prior state is unknown. In the same essay I argued that the residue is what anything arriving through the microscopic boundary must look like from inside the domain. In this essay I add the name of what arrives. From the omniscient side, the side of pattern and prediction, hard randomness is what comes through the microscopic boundary: the incompressible, the unaccounted-for, what is left after every regularity has been extracted. From the transcendent side, the side of potentiality and the new, creation is what comes through the microscopic boundary. Hard randomness and creation are one thing under two descriptions, and the two descriptions differ because the two descriptions are made from two different modalities, the omniscient and the transcendent. Randomness is the name the world gives to what the self would call novelty. "Randomness" is the description from the side of the world, the omniscient side. "Novelty" is the description from the side of the self, the transcendent side.

Second, why must the transcendent appear as indeterminacy, rather than as anything else, when the transcendent enters a domain? The answer is that the domain is a domain of comparison. Every comparison requires a content that is the same or different within or across a context, but anything new has no prior content against which the new thing can be compared. The new cannot be predicted, because prediction extends a known pattern, and the new is exactly what lies outside the known pattern. Nor can the new be observed as a completed object, because observation converts context into content and what observation converts is actual, no longer potential. So from inside a domain, at the boundary where the new comes in, one finds precisely an event whose outcome nothing within the domain fixes. When nothing within a domain fixes the outcome of an event, we call the event "indeterminate". The indeterminacy of a quantum event is the sign that something has arrived that the domain did not contain, and not a failure of the domain to specify the outcome.

At this point I part from the two familiar interpretations of quantum indeterminacy, the epistemic interpretation and the brute interpretation. On the first familiar interpretation, the indeterminacy is epistemic: the

quantity has a definite value, and we do not know the value. In the essay on hard randomness I said why, after the loophole-closing tests of Bell's inequality, the epistemic interpretation requires more of the world than the alternative requires. On the second familiar interpretation, the indeterminacy is simply brute: each outcome is a random draw with no further character. My reading agrees with the second interpretation that there is no hidden value, and that no prior state fixes the outcome. But on my reading the residue has a character, the character of the transcendent. The residue is potential becoming actual at the one place in a domain where potential can become actual without having been actual before: the microscopic boundary.

III. The Aggregate, and the Second Axiom

Third, how does the aggregate of many quantum events turn indeterminacy into order? In *An Immanent Metaphysics* I say that the strength of a creative manifestation is defined in terms of the degree of organization and coherency of large numbers of microscopic eventualities. In the same book I say that the examination of any small finite collection of microscopic eventualities will have a lesser appearance of potentiality than that of the entire aggregate. In plainer words, a creative manifestation is stronger when the many small events that make up the manifestation are more organized and more coherent, and a few of those small events, looked at alone, show less potentiality than the whole aggregate shows.

The relation between the few events and the whole aggregate has a precise form in the second axiom. A class of the transcendent will precede an instance of the immanent. A class of the immanent will precede an instance of the omniscient. A class of the omniscient will precede an instance of the transcendent. When the second axiom is read into physics, the axiom says three things, in the order of the directed cycle from the omniscient to the transcendent to the immanent and back to the omniscient. Many macroscopic structures, taken together as the known world,

precede one encounter with what exceeds the structures (a class of the omniscient precedes an instance of the transcendent). Many microscopic potentialities precede one actual interaction (a class of the transcendent precedes an instance of the immanent). And many actual interactions precede one macroscopic structure (a class of the immanent precedes an instance of the omniscient). The macroscopic object is the thing that exists, that persists, and that can be measured again and again. The macroscopic object is an instance of the omniscient. The second axiom says that a class of the immanent, a multitude of interactions, precedes the macroscopic object, and that a class of the transcendent, a multitude of potentialities, precedes each of those interactions in turn. A macroscopic structure is the order that many microscopic events show together: the macroscopic is built on the microscopic as a pattern is built on a population of events, and not as a house is built on a foundation.

The second axiom is the reason that a single quantum event shows minimal organization and the aggregate shows order. A single event is one instance drawn from a class of potentialities. So there is nothing yet for the single event to be coherent with. Many events interacting with one another make up the class of the immanent from which an omniscient instance, a structure, can arise. Coherence is a property of many events together, not of one event. Now I say something that goes against a common intuition, the intuition that order in the world suppresses creation. The order of the macroscopic world is the manifestation of creation, the form in which creation shows itself. The order of the macroscopic world is not the suppression of creation. The strength of the creative aspect is measured by the degree of organization of the aggregate, and not by the disorganization of the individual event. A world of uncorrelated quantum events would be a world in which potentiality had entered and nothing had been made of the potentiality, and so a world of uncorrelated quantum events would not be a highly creative world. Creation enters through the small and shows itself in what the many small events together become.

On What This Reading Does Not Say

My reading does not say that the metaphysics predicts the statistics of quantum events, the form of the Born rule (the rule that states the probability of each outcome of a quantum measurement), or the rate at which coherence among many events builds into classical order. All three are matters for physics: the statistics, the Born rule and the rate. Physicists have an extensive account of all three under the heading of decoherence. Decoherence is the process in which the constant interaction of a quantum system with its surroundings destroys the system's combination of possible outcomes. My reading says why there is an aggregate order at all, and why a single event does not show the aggregate order. The reason is that the macroscopic is an instance of the omniscient, that the second axiom places an instance of the omniscient after a class of the immanent, and that the second axiom places each instance of the immanent after a class of the transcendent. My reading is a reading of the shape of the order, of what comes before what, and not a reading of the numbers.

IV. The Uncertainty Relation as an Instance of the Theorem

I state the Incommensuration Theorem in full in the Introduction. For this section I need only the two forbidden conjunctions of the Incommensuration Theorem. When the four compounds (symmetry, asymmetry, continuity and discontinuity) are applied absolutely and together, symmetry cannot be conjoined with continuity, and asymmetry cannot be conjoined with discontinuity. To be applied absolutely is to hold exactly, at the foundation of a description. Symmetry is sameness of content across difference of context, and continuity is sameness of content within sameness of context. Asymmetry is difference of content across difference of context, and discontinuity is difference of content within sameness of context. Within any finite domain the two members of each forbidden pair occur together to finite degree but cannot both be perfected at once.

The uncertainty relation of the physicist Werner Heisenberg says that the product of the uncertainty in a particle's position and the uncertainty in the particle's momentum cannot fall below a quantity fixed by the Planck constant. Narrow the one uncertainty and the other uncertainty widens. Neither position nor momentum can be made exact while the uncertainty in the other remains finite. In the essay on hard randomness I read the uncertainty relation as a limit of access, a limit on what any measurement can obtain, and in the essay on the three horizons I read the number, the Planck constant, as marking the location of the microscopic boundary. In this essay I read the uncertainty relation itself as an instance of the first forbidden conjunction, the conjunction of symmetry with continuity. By the uncertainty relation itself I mean the fact that position and momentum, and not some other pair, are the two quantities that cannot both be perfected.

In the foundation volumes I take three routes to this reading, and the three routes agree. The foundation volumes are the earlier books on which this volume rests.

The first route is the argument from the trajectory. When a body has a definite position and a definite momentum at every instant, the body has a trajectory. Suppose a trajectory is specified at every instant with no gap, under one law that holds everywhere. Then the trajectory is continuity and symmetry perfected together in what is found (in the findings, as distinct from the formalism that describes them). Continuity and symmetry perfected together is the first forbidden conjunction. In quantum theory physicists keep what they find exact, in whole steps with exact labels, and give up the trajectory. Giving up the trajectory shows as the bound on how sharply position and momentum can be known together, and Planck's constant sets the size of the bound (*Measurement*, Chapter 5).

The second route is the argument from the pairing of the two survivors. Physicists tie momentum to symmetry more directly than they tie any other quantity to symmetry. The mathematician Emmy Noether proved the theorem that physicists call Noether's theorem. By Noether's theorem,

the conservation of momentum is the consequence of the invariance of the laws under spatial translation: the laws stay the same when everything is moved from one place to another. A state of exactly definite momentum is a state that is the same at every position, apart from its phase (the point that the wave has reached in its cycle), and physicists call a state of this kind a plane wave. The plane wave is symmetry of momentum with discontinuity of position, and the plane wave has given up its localization entirely. A state confined in place is continuity of position measurement, a sameness of spatial context, paired with asymmetry of momentum, a difference of dynamic content (*Incommensuration*, Chapter 15). So the uncertainty relation pairs the two survivors, one survivor at each end of the trade-off, and never pairs the forbidden pair.

The third route is the argument from the mathematical form of the uncertainty relation. Position and momentum are a conjugate pair under a Fourier transform, the mathematical operation that turns a description of a state by position into a description of the same state by momentum. The conjugate form of position and momentum is the conjugacy of the omniscient and the transcendent in the first axiom, which says that the omniscient and the transcendent are in conjugate relationship to one another. The first axiom is derived as a theorem from the Incommensuration Theorem, and so the uncertainty relation is an outcome of the Incommensuration Theorem (*Incommensuration*, Chapter 15).

There is also a separate point, apart from the three routes: no state can be both the same across every place and confined to one place. Sameness across every place is symmetry, and confinement to one place is asymmetry. Symmetry with asymmetry is an opposite pairing, and under the rule of the Incommensuration Theorem against opposite pairings, opposites applied absolutely are incompatible. So the joining of symmetry with asymmetry is already excluded.

I want to mark carefully what my reading contributes and what my reading borrows from physics. My reading contributes the claim that the pairing of position and momentum is not accidental. Position and momentum are the two quantities that cannot both be known exactly togeth-

er because a trajectory would perfect continuity and symmetry at once, and under the Incommensuration Theorem continuity and symmetry cannot both be perfected. My reading borrows three things from physics: the existence of a bound, the size of the bound, and the mathematical form of the uncertainty relation. Nowhere in this essay do I say how large Planck's constant is, because the number of Planck's constant expresses a unit.

My reading also generalizes in the way the physics generalizes. In every conjugate pair, such as energy and time or angular momentum and angle, an invariance across contexts is paired with a specification within one context, and each conjugate pair carries the same bound for the same structural reason.

The Survivors, at the Small Scale

The pairings that the Incommensuration Theorem permits are as instructive as the pairings that the theorem forbids. The two valid absolute conjunctions are continuity with asymmetry and symmetry with discontinuity. A localized wavepacket is a wave confined to a small region, with a definite enough position and a phase that varies from point to point, and so the localized wavepacket is continuity with asymmetry. The plane wave is the same everywhere and countable in its excitations, and so the plane wave is symmetry with discontinuity. A mode is one definite pattern of vibration, and the discrete quantum of a definite mode is symmetry with discontinuity for the same reason. In the essay on the wave and the particle, in Part II, I read the two survivors, as the wavepacket and the plane wave show them, as the two faces of quantum matter. The uncertainty relation is the statement that physics can have either survivor perfected but never the forbidden pair, and the statement that between the two survivors there is a continuum of finite trade-offs. The continuum of finite trade-offs is exactly the qualifier of the theorem: within a finite domain, both members of a pair occur to finite degree.

V. Clarity and Creation

In *An Immanent Metaphysics* I give a further characterization of creation. The further characterization says something about which physical systems show the creative aspect most. To be clear is to allow creation. The degree of the creative aspect is proportional to clarity and transparency, to emptiness, to potentiality, and inversely proportional to simplicity.

The characterization requires the distinction that I draw between simplicity and clarity, two qualities that people often confuse. A simple system is a system with few parts and few relations. So a simple system is easy to specify completely. A clear system is a system that transmits: what enters a clear system can pass through the system and be made into something. A diamond and a lump of coal are both carbon. The coal is simpler in structure and admits no light, while the diamond is more organized and transmits nearly all of the light. So the diamond, and not the coal, is the figure for a reality that admits the new. A reality that admits the new is like the diamond, organized and transmitting, and not like the coal, simple and closed to light.

I read the characterization into physics, cautiously. Consider first a simple, closed, fully specified system such as a single two-level system (a quantum system with only two states) in an isolating trap. Physics comes nearest to exact prediction for a system of this kind. A system of this kind also has the least creative aspect. Potentiality enters the two-level system, because the two-level system is a quantum system and has a microscopic boundary like any other system, but in the two-level system there is nothing for what enters to become. Consider next a complex, open, interconnected system: a system with many parts in many relations, in exchange with its surroundings, for which physics predicts least exactly and in which novelty most appears. In the terms of the framework, the least exact

prediction and the greatest novelty are one fact, not two. The system that is hardest to specify is the system that transmits most, and what the system transmits is what came in through the small.

I hold this reading of clarity more loosely than the reading of the uncertainty relation. The relation between complexity and unpredictability is a commonplace of physics, and physicists need no metaphysics to observe the relation. What I add from the framework is the reason for the relation: clarity and creation vary together. I offer the reason as an interpretation, and not as a result that physics is obliged to accept.

VI. The Three Mysteries as Physics Meets Them

In the essay on the three horizons I established that the unknowable, what cannot be known even in principle, has a shape: there are three places where the knowable gives way to the unknowable. The three places are the macroscopic horizon, omniscient in modality; the microscopic limit, transcendent in modality; and the surface of unconsciousness, the horizon past which the self cannot see itself, immanent in modality. The three places are the three mysteries: the Mystery of the Horizon, the Mystery of the Infinitesimal and the Mystery of the Subconscious. I take the count of three, and the alignment of each place with its modality, as given. I add three points about where the three mysteries appear in physics.

The first point concerns the second axiom applied to the three categories of knowledge: the known, the unknown and the unknowable. When the three categories are considered from the impersonal, objective perspective, the known has the nature of the omniscient, the unknown has the nature of the immanent, and the unknowable has the nature of the transcendent. The directed cycle of the second axiom then says that many instances of the known precede one encounter with the unknowable, that many encounters with the unknowable precede one engagement with the unknown, and that many engagements with the unknown precede one item of the known. Inquiry in physics has the shape of the directed cycle

of the known, the unknowable and the unknown. Knowledge accumulates, and at some depth of accumulation the accumulated knowledge shows a boundary that no further accumulation will cross. When physicists come up against that boundary, they turn back to the unknown, to what has not yet been measured, with renewed engagement, and from the renewed engagement new knowledge arises. The uncertainty relation was an encounter with a boundary of exactly this kind. Physicists knew a great quantity of physics, such as mechanics, optics and the spectra of atoms, before they recognized that something was structurally unspecifiable. After the recognition, physicists redirected their inquiry, and they did not end their inquiry.

The Dual Perspective

In *An Immanent Metaphysics* I note that the modal assignments of the three categories of knowledge shift when the perspective shifts from the impersonal to the personal. From the first-person view, the known is immanent: the known is what I am in contact with, here and now. From the first-person view, the unknown is omniscient: the unknown is the vast body of structure that I have not explored, which is there whether or not I explore it. From the first-person view, the unknowable remains transcendent. The content of the triple is the same in both views. When the perspective from which the roles are assigned changes, the known and the unknown exchange roles, and the unknowable keeps its place. An exchange of two roles is not a rotation, a shift of all three roles one step around the cycle. If the exchange were carried through the second axiom, the exchange would run the cycle in reverse, and so I read the cycle of the second axiom in the impersonal focus only. The shift of the modal assignments with perspective is itself an instance of a principle that applies throughout the framework: a modal assignment is made with respect to a context of consideration, and is not a label fixed to a thing. For physics, the practical consequence of the dual perspective is small but real. What is known to the discipline of physics, the omniscient body of results, is for any one physi-

> cist mostly unknown. What any one physicist knows is the part of the omniscient body of results that the physicist is in contact with. So the discipline and the person do not have the same known.

The second point concerns what the microscopic limit is, as a mystery. In *An Immanent Metaphysics* I call the microscopic limit the mystery of the infinitesimal: that scale at which knowledge of definite state or quality becomes impossible. In the same book I name the uncertainty limit, the bound in the uncertainty relation, as the physical expression of the mystery of the infinitesimal. Below the scale of the infinitesimal, structural knowledge is structurally foreclosed (ruled out by the structure of comparison itself) and not merely lacking. The microscopic limit is the hard boundary, the boundary between the unknown and the unknowable. The microscopic limit is hard for the reason stated in Section II: what comes through the microscopic limit is what the domain did not contain, and no accumulation of what the domain contains will reach the microscopic limit, or reach what comes through the limit. The soft boundary is the boundary between the known and the unknown, and physicists move the soft boundary every year. Physicists do not move the hard boundary. As instruments improve, an instance of the hard boundary recedes, but the receding of the instance does not move the hard boundary as a class.

The third point concerns what happens to a person who comes up against the hard boundary. In *An Immanent Metaphysics* I say that mystery is neither conserved nor diminished by any degree of knowing, understanding, reason, or science. A physicist who understands general relativity is not less awed by the universe than a shepherd who knows nothing of physics. The content of the awe changes. The awe itself does not diminish. Deeper knowledge produces, if anything, deeper awe, because the known shows more precisely and more vividly the contours of what is not known and cannot be known. I take the deepening of awe to be a plain description of what happens to the people who work at the boundaries of physics, and not a consolation offered to them. The reason that knowing does not diminish mystery is structural. In *An Immanent Metaphysics* I call

the reason the veil of secrecy: the omniscient cannot contain or observe the transcendent. One cannot know the transcendent from within the omniscient, because knowing is itself an interaction, and so knowing is immanent. Only the transcendent can perceive the omniscient, and the omniscient can never perceive the transcendent. Each result added to physics is an increase in the omniscient, and every increase in the omniscient increases the surface across which the transcendent is met and does not decrease, by any amount, what remains on the other side of the surface.

VII. Created or Discovered?

I close with a question that physicists ask about their own laws. I answer the question from the theory of creation. Are the laws of physics discovered or created? Was the uncertainty relation found in nature, or made by the minds that framed quantum mechanics?

In the terms of the framework, I say that the question, as posed, has no answer independent of a choice. I also say which choice the answer to the question depends on. Whether something is called created or discovered depends on the placement of the boundary of the self. Consider the totality of all being, and divide the totality into self and not-self. What one will say depends on where one draws the line between self and not-self. If one takes all of being as subjective (the position of idealism), one will assert that one has created everything, the laws of physics included. If one takes all of being as objective (the position of realism), one will assert that one has created nothing and has discovered whatever one has. Neither extreme is valid. I say why in the section of *An Immanent Metaphysics* on the errors of extrema. So the distinction between created and discovered depends on where the boundary of the self is drawn, and is not a feature of the thing.

That dependence has a specific consequence for physics. A law of physics is a symmetry, a sameness of content across difference of context, and a symmetry is omniscient: a symmetry is the same for every observer,

and being the same for every observer is what makes a symmetry a law. So a law, taken as a law, is on the far side of any boundary of self that a single physicist could draw, and in that respect the law is discovered. But the framing of the law is an act of the transcendent. The framing of a law is the choice of what to compare with what: for the uncertainty relation, selecting position and momentum rather than some other pair, and deciding that one regularity, and not another, is the one worth stating. Creation is cooperative across the whole community that made the framing, and in that respect the law is created. The law is discovered as symmetry and created as the comparison in which the symmetry was found. Both descriptions are right, and neither description is complete, because the boundary of self that would make either description complete cannot be drawn.

VIII. Summary

Three claims of this essay are at the depth of the metaphysics itself: that creation is transcendent, that the microscopic boundary is transcendent, and that the second axiom orders the small, the interactive and the structural. Three other claims are readings of known results: that quantum indeterminacy is creation entering through the microscopic boundary, that macroscopic order is the aggregate the second axiom requires, and that the uncertainty relation is an instance of the first forbidden conjunction. Each of the three readings states the structural reason for its result. Section VII has no bearing on any physical claim.

Creation is not an event, and creation has no place. But a domain has a boundary at the small end, the microscopic boundary. The microscopic boundary has the nature of the transcendent. What is transcendent to a domain enters the domain at the microscopic boundary. From inside the domain, the entrance looks like indeterminacy: an event whose outcome

nothing within the domain fixed. From the side that the entrance came from, what enters is the new. Indeterminacy and the new are one thing under two descriptions.

A single event shows minimal organization because a single event is one instance of a class of potentialities. The aggregate shows order because many interactions make up the class from which a structure can arise. In physics, the second axiom is the minimal organization of the single event together with the order of the aggregate. The order of the world is what the many small events together become, and not the suppression of what enters through the small.

The uncertainty relation says that position and momentum cannot both be known exactly together, and the Incommensuration Theorem says why. In a trajectory, every position and every momentum is fixed at every instant under one law, so a trajectory is continuity and symmetry perfected together in what is found, and that conjunction is forbidden. Physics supplies the bound. The framework supplies the reason that there is a bound.

At the hard boundary, knowledge turns back toward the unknown, and does not end. Many things known show one thing unknowable. The encounter with the unknowable returns physicists to the unknown, and new knowledge comes from the unknown. The awe of the physicist does not diminish, because nothing added on the near side of the hard boundary makes smaller what is on the far side. The physicist and the shepherd stand before the same mystery: the same unknowable lies beyond what each of them knows. The physicist sees the outline of the mystery more clearly. Seeing the outline more clearly is all the difference between the physicist and the shepherd. The difference is not a small one.

KEY CONCEPTS IN THIS ESSAY

- **Microscopic boundary**: the limit of a domain at the small end, transcendent in modality; the place through which creative potentiality enters a domain, at no particular position.

- **Creation**: the transcendent aspect of all events; real but not existing; not actual, not observable, not conserved, not repeatable; without source or location.
- **Quantum indeterminacy**: the physical expression of creation entering through the microscopic boundary; an event whose outcome nothing within the domain fixes; hard randomness seen from the transcendent side.
- **The aggregate**: the class of many interactions from which macroscopic structure arises; the strength of the creative aspect is measured by the organization of the aggregate, not by the disorganization of the individual event.
- **The second axiom in physics**: many structures precede one encounter with what exceeds the structures; many potentialities precede one interaction; many interactions precede one structure.
- **Uncertainty relation as instance**: three routes agree. By one route, a trajectory would perfect continuity and symmetry together in what is found. By another route, the uncertainty relation pairs the two survivors and never the forbidden pair. By the third route, the Fourier form of the uncertainty relation is the conjugacy of the first axiom. Physics supplies the bound.
- **Clarity and creation**: the creative aspect is proportional to clarity and transparency and inversely proportional to simplicity; the diamond, not the coal, is the figure for a reality that admits the new.
- **The three categories of knowledge**: the known (omniscient), the unknown (immanent), the unknowable (transcendent), from the impersonal perspective; from the personal perspective the known and the unknown exchange roles and the unknowable keeps its place: a flip, mediated by Axiom I, and not a rotation.
- **Hard and soft boundaries**: the boundary between known and unknown is soft and moves with inquiry; the boundary between unknown and unknowable is hard and does not move.

- **Veil of secrecy**: the omniscient cannot contain or observe the transcendent; only the transcendent perceives the omniscient; hence mystery is not diminished by knowing.
- **Created or discovered**: a distinction that depends on where the boundary of the self is drawn, not on the thing; a law is discovered as symmetry and created as the comparison in which the law was found.

Materials Reviewed

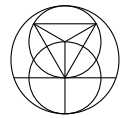
Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorism 1.3-1 (the three axioms); aphorisms 1.72-14 and 1.73-1 through 1.73-17 (the theory of creation; the microscopic boundary; clarity and creation); aphorisms 2.71-2 through 2.71-7 (the known, the unknown, and the unknowable); aphorisms 2.72-1 through 2.72-8 (the Great Mystery; the three mysteries; mystery not diminished); aphorism 2.74-1 (the veil of secrecy); the section "Errors of Extrema"; the Technical Appendix, "The Incommensuration Theorem."

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapters "The Theory of Creation" and "The Known, the Unknown, and the Unknowable."

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

Kennard, Earle H. "Zur Quantenmechanik einfacher Bewegungstypen." *Zeitschrift für Physik* 44 (1927): 326–352.

Noether, Emmy. "Invariante Variationsprobleme." *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse* (1918): 235–257.



Essay 17

What Physics Cannot Reach

Physics as Instance, Metaphysics as Basis, and the Framework's Own Blind Spot

ABSTRACT

Every theory is a triple: an object domain (what the theory is about), a model domain (the symbols and equations in which the theory describes its object), and a correspondence domain (the links between the object domain and the model domain). In the triple, the object has the nature of the transcendent (the mode of the generative), the model has the nature of the omniscient (the mode of structure), and the correspondence has the nature of the immanent (the mode of process). In this essay I draw the consequences of assigning the three domains to the three modalities. The first axiom says that the immanent is more fundamental than the omniscient and/or the transcendent. So, by the first axiom, the correspondence is more fundamental than either the object or the model. Object and model stand in conjugate relation: each is defined by its relation to the other, and each exceeds the other in a definite way. The physical world always exceeds the formalism of physics, and the formalism always carries structure with no counterpart in the world. Gauge freedom and coordinate artifacts are the physical examples of structure with no counterpart in the world. Gauge freedom is a freedom to change the equations in a way that changes nothing that is measured, and a coordinate artifact is a feature that appears in one choice of coordinates and vanishes in another. From the triple I argue for a reversal of the usual order. I read physics as

an instance of metaphysics, and not metaphysics as a speculative extension of physics. I also argue that the demand for falsifiability (the demand that some observation could show a claim to be false) is proper to explanation and prediction, which answer the questions why and how. When the demand for falsifiability is applied to description, which answers the question what, the demand is a category error. Description is the work that metaphysics does. I then apply the Incommensuration Theorem to the framework itself, the metaphysics of comparison on which this book rests. A structural description is symmetric with what it describes. Therefore, by the Incommensuration Theorem, a structural description cannot be perfectly continuous with what it describes. So the framework cannot capture the processual dimension of its own enactment (the lived process in which a person discovers and works through the framework), cannot describe the particular values and events of any world, and cannot enter the unknowable, whose boundary the framework marks. I read the three limits as confirmations of the framework rather than failures of the framework. I close by saying what the framework can do from inside its own blind spot, the processual dimension that the framework cannot capture.

Note on framework. This essay depends on the Introduction to this volume for four things: the six intrinsics, the Incommensuration Theorem, the three axioms and the modal alignment. This essay also depends on the essay on the three horizons and the essay on domain constants, the two essays immediately preceding this one. The two essays locate the two physical boundaries of the domain of comparison, at the Planck constant and at the speed of light. In my book *Unlocking Reality*, two chapters contain the triple of theory and the general argument that a theory cannot be continuous with what it describes: the chapter on the basis of theory and the chapter on the limits of the epistemic process. In this essay I build on the two chapters and do not restate the two chapters. Section V of this essay uses the account of the six questions (what, where, how, when, who

> and why) that I give in the essay on the deep why, in Part II. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Triple of Theory

To theorize is to set something one wishes to understand in a structured relation to a framework of terms in which the understanding can be expressed. In the chapter of *Unlocking Reality* on the basis of theory, I resolved the act of theorizing into exactly three components. I recall the three components briefly in this section, because the rest of this essay depends on the modal character of each component, that is, on the modality whose nature each component has. The three modalities, which the Introduction describes, are the immanent, the mode of process; the omniscient, the mode of structure; and the transcendent, the mode of the generative.

The object domain is what the theory is about. The object domain is always richer than any description of the object domain. The object domain contains what the theory captures and what the theory does not capture. The line between the two parts cannot be drawn from within the theory. The object domain has the nature of the transcendent: the object domain precedes the theory, exceeds the theory, and is described in terms of interactions, the events that the theory attempts to represent.

The model domain is the representational structure: the symbols, equations, categories, and formal relations in which the object is described. The model domain is always more structured than the object, more definite and more manipulable than the object. The greater structure is both the strength of the model domain and the limit of the model domain. The model domain has the nature of the omniscient: the model domain is a finished structure, inspectable from outside, checkable for consistency, communicable without loss, and described in terms of relations.

The correspondence domain is the set of links between the object domain and the model domain. Each link says that one element of the model stands for one feature of the object, or that one relation in the model mirrors one relation in the world. The correspondence domain is a domain in its own right, with its own structure and its own constraints. The correspondence domain has the nature of the immanent: the correspondence domain is established through acts of comparison, not given in advance, and the correspondence domain is described in terms of comparisons. Theory is comparison, the comparison of object with model, and the correspondence is where the comparison is made. By the correspondence I mean the practice of comparison in the world, the acts in which someone holds a model against its object. The practice of comparison is immanent. In my book *Category Theory and the Immanent Metaphysics* I place something else with the transcendent: the correspondence of a theory with what the theory is about, taken as a relation laid out. The two placements are placements of different things, the practice of comparison and the relation laid out.

Two consequences for the triple follow from the axioms. The first axiom says that the immanent is more fundamental than the omniscient and/or the transcendent, and that the omniscient and the transcendent stand in conjugate relation to one another. Applied to the triple, the first axiom says that the correspondence domain is more fundamental than either the object domain or the model domain. In the logical sense, the comparison precedes the distinction between what is compared and what that thing is compared with. A theory stripped of its correspondences is a formal game, and an object without correspondences is untheorized experience. Neither the formal game nor the untheorized experience is a theory. The second consequence is the conjugacy of object and model. Object and model are conjugate, which is more than being different. To be conjugate is for each to be defined by its relation to the other across the correspondence, and for each to exceed the other in a direction that the

other cannot follow. I take the two directions in turn: in Section II, the direction in which the world exceeds the model, and in Section III, the direction in which the model exceeds the world.

II. The World Exceeds the Model

Scientific theory is an instance of the general triple. The object domain is the physical world. The model domain is the mathematical formalism. The correspondence domain is the set of interpretive rules that connect the formalism to measurement. An operator is a mathematical object of the formalism, and an observable is a quantity that can be measured. For example, an interpretive rule states that a given operator corresponds to a given observable, that a given coordinate corresponds to a given reading on a given instrument, or that a given term in the equation is the thing the detector counts.

The familiar direction of the conjugacy is the first direction, in which the world exceeds the model. The physical world, which is transcendent, always exceeds the formalism, which is omniscient. No model completely describes its object. I want to say precisely why the incompleteness of every model is not a temporary condition that a better model would remove. The transcendent is the modality of what exceeds specification, and the omniscient is the modality of what is specified. A complete model would be a specification of what exceeds specification, and a specification of what exceeds specification is incoherent, not merely difficult to achieve. Every improvement in a physical theory includes more of the object in the model. After every improvement, the object still exceeds the model, because the excess is what the object is in its modality, the transcendent, and not a quantity that improvement reduces toward zero.

The modal excess of the object is the structural ground for a fact that every physicist knows and that philosophers of science have struggled to state. Physical theories are replaced. When a new theory replaces an old theory, the old theory is usually not refuted within its own domain of cor-

respondence. The mechanics of the physicist Isaac Newton is as good as it ever was wherever the correspondences of Newtonian mechanics hold. The replacement is the discovery that the object exceeded the model in a place that the model could not have shown, because a model is omniscient and so can show only what the model contains. In each replacement, physicists found the excess from the side of the correspondence, from a measurement that failed to correspond. Physicists never found the excess from the side of the model alone.

III. The Model Exceeds the World

People remark less often on the second direction of the conjugacy, in which the model exceeds the world. The model always contains structure that has no counterpart in the object. The surplus structure of the model follows from the same conjugacy, read in the other direction. The omniscient is the modality of structure, of pattern and of relation. A model is a structure through and through. A structure has relations among its own elements whether or not each of those relations stands for anything. The object domain is not the kind of thing that has a relation for every relation in the model, any more than the model is the kind of thing that has an element for every excess in the object.

Physicists have a name for structure in the model that has no referent in the object: physicists call that structure gauge. A physicist can shift the electromagnetic potentials (the quantities from which the electric and magnetic fields are calculated) by the gradient of an arbitrary function, and the shift changes nothing in the fields that are measured. So the shift is real in the model and is nothing in the world. A physicist can also multiply the wavefunction, the quantum description of a system, by a global phase (one shift of phase applied to the whole wavefunction), and the multiplication changes no probability. The global phase is a relation among elements of the model and corresponds to no feature of the object. In general relativity the case of structure without referent is sharper still.

The coordinates in which general relativity is written carry no physical identity of their own. The same physical situation can be described in any coordinates, and features that appear in one description vanish in another. The classic case is the apparent singularity at the Schwarzschild radius in the original coordinates of the astronomer Karl Schwarzschild. A singularity is a place where the equations give infinite values, and the Schwarzschild radius is the radius of the horizon of a black hole. In other coordinates the apparent singularity vanishes. Physicists call a feature that vanishes in another description a coordinate artifact. The practice of physicists is to identify coordinate artifacts and to insist that only what is invariant under the removal of the artifacts is physical.

The practice of identifying coordinate artifacts is correct, and I do not propose to amend the practice. I add from the framework the reason that the artifacts are inevitable. So physicists can expect artifacts in each new theory, rather than be embarrassed by the artifacts. The third axiom says that the modalities are distinct, inseparable, and non-interchangeable. Model and object are of different modalities. Model and object cannot be interchanged, and therefore no mapping between model and object can be one-to-one. A one-to-one mapping would mean that the model could stand in for the object without remainder and that the object could stand in for the model without excess, and standing in for each other in that way is interchangeability. Gauge freedom is the model's remainder: the surplus structure that the non-interchangeability of the modalities requires. In the same way, the unspecified excess of the object is the object's surplus, which the same axiom requires from the other side. So two freedoms are structure with no referent: the freedom of gauge, which is the choice of potential and of global phase, and the freedom of coordinates. The gauge group itself is not surplus. The gauge group is the group of symmetries of the forces, as distinct from the free choice of potential and phase. The gauge group has a referent, the exact charges that are found, and in my book *Non-Commutative Geometry and the Immanent Metaphysics* I derive the gauge group from the structure of comparison. The mathematician Emmy Noether proved two theorems in one paper of 1918. Noeth-

er's first theorem says that every continuous symmetry of a physical law comes with a conserved quantity. Noether's second theorem is the statement in physics of the distinction between the gauge group and the freedom of gauge: a symmetry that depends on arbitrary functions, as a freedom of gauge does, yields no conserved charge of its own but an identity among the equations. If every element of a theory's model corresponded to a feature of the world, the model would have ceased to be a model.

The Map and the Territory, Made Precise

People often say that the map is not the territory, and the saying is true but not informative. The Incommensuration Theorem states the saying precisely. A model is symmetric with its object: the model is the same content, the same structure, presented in a different context, the context of the formalism rather than the context of the world. Being the same content in a different context is what makes a model a representation at all. But the Incommensuration Theorem says that what is perfectly symmetric cannot also be perfectly continuous. The model cannot be, at the same time, a perfect copy of the object and an unbroken continuation of the object, with no gap where the model ends and the object begins. There must be discontinuities between the description and the described. Gauge freedom is one discontinuity between the description and the described, on the side of the model, and the unmodeled excess of the world is another discontinuity, on the side of the object. The correspondence domain is the set of places where the model and the object are joined, and the joining is finite, which is to say that the model and the object are not joined everywhere.

IV. Physics as Instance, Metaphysics as Basis

Usually, people regard physics as the foundational science and metaphysics as a speculative extension of physics: something one might do after the physics is finished, if one had the taste for metaphysics. I reverse the usual order, and the reversal follows from the structure of theory that Sections I to III describe.

People often define metaphysics by negation, as what is not physics. But a definition by negation says nothing about what the thing defined is. If someone defines a thing by what the thing is not, the thing is left entirely uncharacterized. The word "not" has no content of its own. The word "not" provides no positive information about the nature of the thing defined. To say "metaphysics is what is not physics" is like saying "X is what is not Y": the statement says something about Y but nothing about X. A negation says nothing of the thing defined except what the thing is not. So a definition must give a positive characterization of what we seek to understand.

Physics is the study of the interactions within a given domain. Metaphysics is the study of the relationships between domains. The two definitions already show the order of physics and metaphysics. The interactions within a domain presuppose four things: that there is a domain, that the domain has boundaries, that what is inside the domain can be compared with what is inside the domain, and that the comparison has a subject and an object, a content and a context, a sameness and a difference. Each of the four presuppositions is a condition of there being physics at all. None of the four presuppositions is a result of physics.

The order of physics and metaphysics shows also in the terms of the triple. Physics uses a specific object domain, the physical world; a specific model domain, the mathematical formalism; and a specific correspondence domain, the method of measurement. Each of the three domains is an instance of a general concept (object, model or correspondence) that

the metaphysics describes and physics does not describe. From within physics, physics cannot say what a model is, what it is for a model to correspond to a world, what a measurement is such that the measurement links the model and the world, or why the formalism should carry structure that the world does not carry. Physics uses models, correspondences, measurements and formalisms with surplus structure. Physics does not ground any of the four. To ground the four is the work of metaphysics, and the grounding is the basis on which physics rests, not an extension of physics.

I want to head off one misreading of the reversal. The reversal does not say that metaphysics tells physicists what physicists will find. The reversal says that metaphysics describes the structure of finding. In the essay on the limits of the epistemic process in *Unlocking Reality*, I was explicit that the axioms alone cannot tell you what particles exist, what laws hold, or what will happen tomorrow. Taken alone, the axioms say only three things: that any world must involve interaction, that interaction must involve symmetry and continuity though never both perfected, and that the subjective and the objective are co-present in every comparison. In other volumes of my program of research, I reach the form of the physical world (its algebra, its symmetries and its charges) from comparison, by identifications that I state as identifications. The values of the physical world are matters for the relevant sciences, and the singular event is a matter for no description at all. The relation of metaphysics to physics is the relation of a class to its instances. Physics is one of the instances. Physics is an instance of metaphysics in a definite sense: physics belongs to the kind of thing the metaphysics is about, and physics cannot step outside that kind to examine the kind. Being an instance of metaphysics does not mean that every value of physics is deducible from the metaphysics.

I call the structural layer that lies beneath physical theories infra-physics. Infra-physics is the foundation of physics, not a replacement for physics. Infra-physics is the layer of structural necessity on which the contingent facts of physics rest. The questions of infra-physics are what must be true of any possible universe, and what structural features are necessary

for there to be physical law at all. Infra-physics states the constraints that any physical theory must satisfy, regardless of the particular values of the physical constants or the specific forms of the physical laws. The axioms and the structural principles that the essays of this book set out are the infra-physical layer. The axioms and the structural principles are the structural scaffolding on which physics is built. The scaffolding is made of the necessary conditions for measurability, for causal order, and for conservation and symmetry.

The whole of this book is an exercise in the reversal of physics and metaphysics. In each essay I take a result of physics and read the result as an instance of a structure that the metaphysics describes, and I claim that the structure is the reason the result holds. Each reading runs from the basis to the instance. A reading never runs the other way, from the instance to the basis, because the instance cannot see its own basis, any more than an interaction within a domain can see the relation between that domain and another domain. In plain words, the basis of an instance cannot be found from within the instance.

V. Falsifiability and the Category of the Question

Sooner or later, someone raises one objection against every metaphysics: is the metaphysics falsifiable, so that some observation could show the metaphysics to be false? The objection is right about physics and wrong about metaphysics. The objection is wrong about metaphysics because the criterion of falsifiability belongs to a different category of question, and not because metaphysics is exempt from criticism.

In the essay on the deep why, I set out the six questions (what, where, how, when, who and why) and the alignment of the six questions with the six measures (mass, space, force, time, probability and possibility). I need three of the six questions in this section. A why question asks for the principle from which an outcome follows, and the answer to a why question is an explanation. A how question asks for the path by which an out-

come comes about, and the answer to a how question is a prediction: an instruction that yields the outcome when someone follows the instruction. A what question asks what is there, what is meant, or what is the case, and the answer to a what question is a description. The explanatory work of physics is to answer the question why by locating an instance under a law. Locating an instance under a law answers why in the shallow sense that the essay on the deep why identifies. Engineers, and physicists who use physics to predict, answer the question how. The descriptive and definitive work of metaphysics is to answer the question what: what comparison is, what a theory is, what a domain is, what it is for something to exist or to be real.

Now consider what falsifiability requires. When a claim forbids something, we call the claim falsifiable: the claim says that a specified observation will not occur, so that making the observation would refute the claim. Forbidding a specified observation is exactly the structure of an explanation and of a prediction. A law that explains why the apple falls forbids the apple from rising, and an instruction that predicts how the eclipse will occur forbids the eclipse from occurring at another hour. Falsifiability is a criterion of why and how, and a good criterion of why and how.

A description forbids nothing. Two statements of the framework are that comparison has six intrinsics and that a theory is a triple of object, model, and correspondence. Neither statement says that some observation will fail to occur. The framework is saying what is meant: what is there when one looks at the structure of comparing. A description is found adequate or inadequate, and an observation does not refute a description. In *An Immanent Metaphysics* I put the criterion of adequacy directly: a description is evaluated on a basis of a feeling of significance, completeness, and relevance, rather than on the basis of a fixed procedure. Does the description describe what is there? Does the description leave out anything that matters? Does the description bear on what one wanted to understand? The three questions of adequacy are not weaker questions than the

question of falsifiability. The three questions of adequacy are questions of a different kind. One asks the same three questions of a definition, a map, a taxonomy, or a metaphysics.

So, insofar as the metaphysics is descriptive and definitive, the metaphysics is found in every act of comparison, and is not proved as a theorem of a formal system is proved. Logic and proof are themselves comparisons that use the metaphysics. One uses the concept of comparison, or fails to use the concept, and one does not falsify the concept. If the description of comparison is incoherent or incomplete or irrelevant, one says so, and saying so is the criticism proper to the description of comparison. To demand that a description forbid an observation is to ask a what to behave like a why. Asking a what to behave like a why is the category error.

I can put the point about falsifiability by levels, because the word "falsifiable" has two senses. In the conventional sense, a single observation within a domain can contradict a law of that domain. In the conventional sense, metaphysics and the axioms are not falsifiable, because the axioms are not a law of any one domain. In the sense of consequences, the structural results derived from the axioms apply to physics, where an experiment can contradict the structural results. In the sense of consequences, metaphysics is falsifiable when the metaphysics is done by deriving structural results from the axioms (*Comparison*, Chapter 14, Section V).

> **Where the Book's Consequences Meet Experiment**
>
> I do not want the reader to take the category argument (the argument that demanding falsifiability of a description is a category error) as a shield over everything in this volume. The framework itself is description. But in Parts II and III, the readings and the exclusions go beyond description toward explanation. The readings and the exclusions say that a result holds for a structural reason. In the strongest cases, the readings and the exclusions say that something will not be found. A superdeterministic completion would be a deeper theory in which the experimenters' choices were fixed in advance, together with what the particles do. A faithful re-

> versal of time would be a reversal of a process that retraces the original process exactly. No one will find a superdeterministic completion, a signal across the boundary of the domain of comparison, a faithful reversal of time, or a single theory in whose findings both survivors are perfected. The four claims are consequences of the structure of comparison that apply to physics, and in physics an experiment can test the four claims, as an experiment can test any why-shaped claim, any claim that answers a why question. The category argument shows that the description of comparison need not satisfy the demand of falsifiability, a demand that a description cannot satisfy. The category argument does not exempt the consequences of the structure of comparison from experiment, and the category argument should not exempt the consequences.

VI. The Theorem Applied to Itself

The framework is a theory. The object domain of the framework is the relationship between self and reality. The model domain of the framework is the axioms, the modalities, the intrinsics and the Incommensuration Theorem. The correspondence domain of the framework is the system of identifications by which the formal structure is linked to particular domains of experience, and the readings in this book are examples of those identifications. Because the framework is a theory, the framework is subject to what the framework says about theories.

The first thing that the framework says about theories is that the model of a theory is omniscient, that the object of a theory is transcendent, and that the object of a theory exceeds the model of that theory. So, as a structural description, the framework is exceeded by what the framework describes. The first axiom puts the excess in another form: the immanent (practice, process, interaction) is more fundamental than the omniscient (theory, structure, pattern). So the theory of comparison is less fundamental than the comparing that the theory describes.

The Incommensuration Theorem states the excess precisely. As a description, the framework is symmetric with the reality that the framework describes: the framework presents the same structure in the context of a text. By the Incommensuration Theorem, the framework therefore cannot be perfectly continuous with the reality that the framework describes. There are gaps, boundaries and discontinuities between the description and the described. The gaps, boundaries and discontinuities are features of any description whatsoever, including the description in this book, and not failures of the author.

Applying the framework to itself is not circular. Applying the framework to itself is self-referential, and the distinction between circular and self-referential matters. A circular argument uses its conclusion as a premise and so establishes nothing. A self-referential description includes its own activity, the act of describing, within the domain it describes. The framework describes comparison, and the description is itself a comparison. The framework describes the structure of theory, and the framework is itself a theory with that structure. The framework describes the process of correspondence, and the framework's own correspondences are instances of that process. The framework applies to its own application. Conventional theories describe domains that do not include the theories: a theory of gases is not a gas. The framework is unusual, because the object domain of the framework includes the act of theorizing, and so includes the framework. I call the inclusion of a framework in its own object domain self-descriptive closure. Self-descriptive closure is the feature that makes this section possible: the framework can say what the framework's own limits are, because the limits of the framework are instances of what the framework describes.

The self-reference of the framework is the opposite of the self-reference of the logician Kurt Gödel. Gödel's incompleteness is the result that a consistent formal system for arithmetic cannot prove every true statement about whole numbers. Gödel's incompleteness is an instance of the Incommensuration Theorem in the domain of formal systems (*Incommensuration*). Gödel built a sentence that turns a formal system against itself, and

with the sentence Gödel found what the system cannot prove. The self-reference of the framework is confirmatory: describing comparison is itself a comparison. In being made, the description shows the structure of comparison that the description describes. The description closes on itself (applies to itself with nothing left over) at three levels: the intrinsics, the Incommensuration Theorem, and the recognition that the Incommensuration Theorem is itself an act of comparison. A fourth level adds nothing new. No description contains the act of comparing itself: the act of comparing is the ground of the description, and not a further piece of the description (*Category Theory and the Immanent Metaphysics*, Chapters 21 and 23).

VII. The Unknowable, and Where the Boundary Lies

The framework cannot do three things, and the three limits of the framework follow from the three modalities.

First, the framework cannot describe the particular. In other volumes of my program of research, I reach the form of the physical world (its algebra, its symmetries and its charges) from comparison, by identifications that I state as identifications. The values are values of this universe: the masses, the mixings and the strengths of the couplings. The values are transcendent to the framework in the way that the object exceeds the model. And no description reaches the singular event at all: no description says which outcome occurs, or which tomorrow comes. Section IV says why: the relation of metaphysics to physics is the relation of a class to its instances, the values are matters for the relevant sciences, and the singular event is a matter for no description at all.

Second, the framework cannot enter the unknowable. In the essay on the three horizons, I argued that the unknowable is what the structure of comparison does not extend to, and not the not-yet-known. In the same essay I argued that the unknowable has a shape: three horizons, two physical and one subjective. I now add the relation of the framework to the

boundary of the unknowable. The framework does not enter the unknowable. The framework marks the boundary of the unknowable: the framework says where the boundary lies. The framework can say where knowledge ends and the unknowable begins. The framework cannot say what lies beyond the boundary, because to say what lies beyond would be to know what lies beyond. To know what lies beyond would be to bring what lies beyond within the boundary of the known. Then what lies beyond would not have been the unknowable after all. The physical location of the boundary is the pair of extremes that I located in the two preceding essays, the essay on the three horizons and the essay on domain constants. At the small end the boundary is the scale marked by the Planck constant. At the large end the boundary is the scale marked by the speed of light. The Planck constant and the speed of light are the two constants that bound the domain of comparison. Everything that can be measured lies between the two constants. At each extreme, complete specification is impossible by the Incommensuration Theorem, because specification requires a comparison and at the boundary the conditions of comparison are no longer met. The framework says where the limit at the Planck constant and the limit at the speed of light lie. The framework says nothing about what lies past either limit. The black hole is the one place in physics where both extremes apply at once: in a black hole the very large closes on the very small. I treated the black hole in the essay on the three horizons, and in this essay I only point to the black hole. General relativity describes the singularity of a black hole as a conjunction of perfect asymmetry with perfect discontinuity, and the Incommensuration Theorem forbids that conjunction. The horizon of a black hole is one-way because every light-cone (the bound of what a signal from an event can reach) tips smoothly at the horizon, and the Incommensuration Theorem permits a one-way horizon made by smooth tipping. The framework can say that much about the black hole and no more. What replaces the singularity is a matter for physics.

Third, the framework cannot capture the processual dimension of its own enactment. The third limit is the subtlest of the three, and I prepared for the third limit in Section VI. The framework is symmetric and structural: the framework is a description. The enactment of the framework is continuous, processual and lived. The enactment includes the discovering of the framework, the working through of the framework, and the transformations of perspective that occur in a person who comes to see comparison in the way that the framework describes comparison. The Incommensuration Theorem says that the description cannot be perfectly continuous with the process. So the lived experience of the framework cannot be conveyed by the framework. The lived experience can be indicated, pointed toward, and suggested by example and by parable, but the lived experience cannot be structurally transmitted. The limit on transmitting the lived experience is a necessity, and not a defect of presentation. The description and the enactment are dual: the description is symmetric and structural, and the enactment is continuous and processual. The description and the enactment cannot be unified, for the same reason that General Relativity and Quantum Mechanics, the two great theories of physics, cannot be unified. I gave the reason in the essay on cross-modal reach. If both great theories were limits of one theory, that theory would have to have both survivors perfected at once, in what is found by one and the same comparison. The Incommensuration Theorem says that the perfection of both survivors at once is impossible.

VIII. What the Framework Can Do from Its Own Blind Spot

People usually think of a blind spot as an absence. The blind spot of the framework is the processual dimension of the framework's own enactment. The blind spot of the framework is a perspective, not a void, and I want to say what can be seen from that perspective.

From the structural side, the processual is what the theory describes but cannot be. From the processual side, the side of the lived experience of anyone who uses the framework, the theory is what the process uses but is not exhausted by. Each side needs the other to be complete. The need of each side for the other is the conjugacy of the first axiom again. Now the conjugacy applies to the framework and to the practice of the framework. Unlike most theories, the framework says of itself that its structural side and its processual side each need the other. The framework can say that the structural side and the processual side of the framework each need the other because the framework predicts its own incompleteness and says precisely where the incompleteness lies. The incompleteness lies in the gap between the symmetric and the continuous, between the structural and the processual, between the theory of comparison and the act of comparing.

The incompleteness of the framework has two consequences: one for how the framework must be presented, and one for physics. The consequence for presentation is that alongside the structural essays there must be something else (narrative, example, personal encounter), because the processual can be communicated only processually. A book of essays cannot supply narrative, example and personal encounter, and I do not try to supply the three in this book. I say only that narrative, example and personal encounter are required. The consequence for physics is that the division between description and enactment holds of any theory, and of physics in particular. The formalism of physics cannot contain the doing of physics. Consider four parts of the doing of physics: the judgment of which measurement to make, the recognition that a result does not correspond, the choice to pursue one anomaly rather than another, and the moment at which a physicist sees that the model has been exceeded. None of the four is in the model, and none could be, because the four are immanent and the model is omniscient. Physicists have always known in practice that the doing of physics is outside the model, and physicists have sometimes been embarrassed by that fact in principle. In the terms of the framework, there is nothing to be embarrassed by in the fact that the do-

ing of physics is outside the model. The practice of a theory is exactly what the theory cannot capture. So the blind spot of a theory is where the practice of the theory lives.

The deepest self-referential result of the framework is that the framework, which states the limits of all theories, states its own limits as an instance of those limits. The limitation of the framework is a confirmation of the framework, not a refutation. If a framework claimed to have no blind spot, then that framework would be claiming to be both perfectly symmetric with its object and perfectly continuous with its object. Being both perfectly symmetric and perfectly continuous with an object is the one thing that the Incommensuration Theorem says cannot be. The closure of the framework as a description, together with the act of comparing that no description encloses, is the evidence for the framework.

IX. Summary

Five central claims of this essay are at the depth of the metaphysics itself: the triple of theory, the conjugacy of object and model, the reversal of physics and metaphysics, the placing of falsifiability by levels, and the Incommensuration Theorem applied to itself. One claim of this essay is a reading of a known feature of physical theories: the reading of gauge freedom and coordinate freedom as structure with no referent. In this essay I make no structural exclusion of my own beyond the structural exclusions made in the essays that I cite in this essay. I do not claim that physics is subordinate to metaphysics in practice. The reversal is a reversal of logical basis, and in physics physicists do what metaphysics cannot do, which is to find the particular.

A theory is an object, a model, and a correspondence between the object and the model. The correspondence is more fundamental than either the object or the model. Object and model are conjugate, and each exceeds the other. The world exceeds the formalism, and the formalism carries

gauge and coordinate structure that corresponds to nothing in the world. Neither excess is a defect. Both excesses are what non-interchangeable modalities look like when the modalities are joined.

Physics studies the interactions within a domain. Metaphysics studies the relations between domains. Physics is an instance of metaphysics and not the reverse, because physics uses the concepts of object, model, and measurement and cannot ground the three concepts. To demand that metaphysics be falsifiable is to ask a description to forbid an observation, which is to ask a what to behave like a why, and so the demand is a category error. But the exclusions that this book makes are why-shaped, and through their consequences experiment can test the exclusions.

The framework is a theory, and so the framework is subject to itself. The framework is symmetric with what the framework describes, and therefore the framework is not continuous with what the framework describes. The framework cannot describe the particular, cannot enter the unknowable, and cannot convey the process of its own discovery. The framework predicted all three limits and located all three limits. A limitation that a theory predicts of itself is an instance of the theory, and not an objection to the theory. Physics cannot reach its own basis, because the basis of an instance cannot be found from within the instance, and metaphysics cannot reach its own practice, because a description cannot capture its own enactment. The reach of each ends where the other begins. Physics and metaphysics meet in one place: the correspondence, the comparison, the measurement. The meeting place is more fundamental than either physics or metaphysics. The meeting place is where physics is done. The meeting place is also where I have written this book from, and where this book stops.

KEY CONCEPTS IN THIS ESSAY

- **The triple of theory**: object domain (transcendent), model domain (omniscient), correspondence domain (immanent); distinct, inseparable, non-interchangeable.

- **Correspondence as basis**: by the first axiom the correspondence domain is more fundamental than either object or model; theory is the comparison, not the model and not the object.
- **Conjugacy of object and model**: the world exceeds the formalism and the formalism exceeds the world; each surplus is guaranteed by the non-interchangeability of the modalities.
- **Structure without referent**: gauge freedom, global phase, coordinate artifacts; omniscient structure in the model with no transcendent counterpart in the object; inevitable, not accidental.
- **Physics as instance**: physics studies interactions within a domain, and metaphysics studies the relations between domains. Physics uses the concepts of object, model, and measurement, and physics cannot ground the three concepts.
- **The category argument**: falsifiability is a criterion for explanation and prediction, for why and how; description, the what, is judged by significance, completeness, and relevance; demanding falsifiability of description is a category error.
- **Self-reference without circularity**: the object domain of the framework includes the act of theorizing; the description of comparison in the framework is itself a comparison; the framework applies to its own application.
- **The theorem applied to itself**: a description is symmetric with what it describes and so cannot be perfectly continuous with it; the framework cannot capture the processual dimension of its own enactment.
- **The three limits**: the framework cannot describe the particular values and events of a world, cannot enter the unknowable, cannot convey its own process; each follows from a modality.
- **Limitation as confirmation**: the theory that identifies the limits of all theories identifies its own as an instance; a framework claiming no blind spot would violate the theorem.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.1-1 through 1.1-4 (the nature of metaphysics; physics as an instance of metaphysics; non-falsifiability); aphorism 1.3-1 (the three axioms); aphorism 1.42-5 (the intrinsics of comparison); aphorisms 1.53-1 through 1.53-3 (theory as triple); the Technical Appendix, "The Incommensuration Theorem," "Consistency and Completeness," and "The Scope of Theory."

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications. The chapters "The Basis of Theory" and "The Limits of the Epistemic Process."

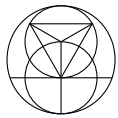
Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications. The chapter on the six types of questions.

Popper, Karl R. *The Logic of Scientific Discovery.* London: Hutchinson, 1959.

Gödel, Kurt. "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I." *Monatshefte für Mathematik und Physik* 38 (1931): 173–198.

PART V

Computation and the Continuum



Essay 18

The Continuum Argument Against Simulation

The Principle of Identity, Cantor's Diagonal, and What No Discrete Computation Can Capture

ABSTRACT

The question of whether this universe could be a computation looks at first like a question about computers, but in fact the question is about whether what exists is, at bottom, continuous or discrete. A question about what exists at bottom is a question about the nature of the real. In this essay I develop the continuum argument from first principles: the argument that a continuous world holds what no discrete computation can hold. I begin with the Principle of Identity: what no conceivable test can distinguish must be regarded as the same. The Principle of Identity turns the simulation question into a search for a test in principle rather than a test in practice. A test in principle is a test whose logic is sound whether or not any instrument can perform the test. I examine two natural candidate tests, repetition and simultaneity, and I find that both fail, but the way the two tests fail narrows the inquiry to a single axis: continuity against discontinuity. Cantor's diagonal argument then supplies the decisive distinction. The continuum holds information that no listing can reach (no list, however long, contains all of the information), while every computation produces only states that can be listed, however large the computation. What can be listed falls short of the continuum, and the shortfall is structural. Real systems are sensitive to their initial conditions, and the

sensitivity of real systems is the mechanism that amplifies the structural shortfall into a difference between two worlds: the world and a simulation of the world. I derive the continuity of the context of every comparison in the foundation volumes, the three books on which this volume rests. The arena of space and time has been found smooth at every scale yet probed. The smoothness of the arena is the physical evidence for the continuity of context. The continuous wavefunction of quantum mechanics shows that a continuous framework is needed for discrete findings. I close by placing what can be listed and what no listing reaches within the relationship of symmetry and continuity. I also state that subjectivity is, at its foundation, continuity with asymmetry. No listing can capture continuity with asymmetry. I dissolved the simulation hypothesis in my book *Third Resolutions in Western Philosophy*, by a different route to a compatible conclusion, so in this essay I take the other route and do not restate the argument of *Third Resolutions in Western Philosophy*.

Note on framework. This essay depends on three other parts of this volume: on the Introduction for the Incommensuration Theorem and the modal alignment, on the essay in Part I on symmetry and continuity as the two types of law, and on the essay in Part II on hard randomness. This essay also refers to my essay on the simulation hypothesis in *Third Resolutions in Western Philosophy*, which argued from the bound triple. The bound triple is hard randomness, temporal direction and subjectivity. None of the three can be imported without the other two. I also refer forward to the essay on computationalism, which comes next in this volume. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Question Beneath the Question

There has been a long debate about whether this universe rests on something fundamentally digital, so that the universe could in principle be encoded the way a hologram encodes a scene. People on the other side of the debate hold that the universe rests on something more like what physics has always called continuous space. To put the question plainly, suppose a computer of any size one likes, with a processor of unbounded speed and memory without limit. Suppose someone wrote for that computer a simulation of the physical universe that honored every law we know: the field equations of relativity, the equations of motion of quantum mechanics, and the statistics of thermodynamics. Could the simulation be made indistinguishable from this world?

Continuity is the idea that space and time possess an infinite smoothness. If the simulation could be made indistinguishable from this world, then continuity would be at best a convenient way of describing the world and at worst an illusion. If the simulation could not be made indistinguishable from this world, then something about the nature of what exists is deeper than any simulation, and more basic than anything that can be held in discrete logic alone.

Both possible answers are claims about what exists, and so the simulation question is not about computers. The simulation question is about the fundamental nature of the real. Either answer to the simulation question is a metaphysical claim. The simulation question serves well as a doorway into the framework of this book, the metaphysics of comparison, for two reasons. Working through the simulation question trains the mind in the kind of abstraction that the framework requires, and the question also yields a result of real significance on its own. The result is that the relationship between the knower and the known, between self and reality, is

intimately bound to the relationship between symmetry and continuity. In this essay I follow the connection between the two relationships, step by step.

II. The Principle of Identity

The continuum argument depends on a principle older than any of the physics that the argument concerns. The Principle of Identity says that what is indistinguishable must be regarded as the same. If no test that could be conceived even in principle would separate two situations, then it is not reasonable to treat the situations as two. If a distinctness could never show itself in any comparison whatsoever, the distinctness is not distinctness at all, but a name with nothing behind the name.

The Principle of Identity is a consequence of what comparison is, and not a physical law. In a comparison, content is what is compared, and context is the respect in which the two things compared are two. To say that two things differ is to say that some content differs within some shared context, which is exactly to say that some comparison could register the difference. Where no comparison could register a difference, the claim that the two things differ is empty. The Principle of Identity therefore belongs to the metaphysics of comparison on which this whole volume rests, so the principle does not need to be brought in from anywhere else.

When the Principle of Identity is applied to the simulation question, the principle has two consequences. First, the Principle of Identity sets the standard for an answer. Suppose a simulation were so perfect that no conceivable test could show a difference between the simulation and a continuous reality. Then simulation and reality would not be two kinds of thing. The hypothesis that we are simulated would be idle: neither true nor false, but empty. Second, the Principle of Identity sets the standard at the level of principle and not at the level of practice. People often miss the second consequence. The force of the continuum argument depends on whether a distinction can be drawn at all, and not on what instruments we

own. If a distinction between a simulation and a continuous reality exists, then simulation and continuous reality are not the same kind of thing, whether or not anyone could ever perform the decisive measurement.

The simulation question then becomes precise. Is there a test, definable in principle and sound in its logic, that would distinguish a discrete simulation from a continuous reality? If there is a sound test in principle, then a discrete simulation and a continuous reality are different in kind. If there is no sound test in principle, then the simulation question dissolves. We learn something from either answer.

III. Two Candidates That Fail

Repetition and simultaneity are the two candidate tests that come to mind first whenever the simulation question is asked, and both tests fail, but the way the two tests fail shows where to look for the distinction that succeeds.

The first candidate is repetition. Perform the same action again and again, and observe whether the results are perfectly identical. One supposes that in a computation identical inputs yield identical outputs, whereas in a continuous world the passage of time alone guarantees that no two moments are ever exactly the same. The repetition test is inconclusive. A simulation of any sophistication can carry a source of variation designed into the program, so the small differences we would look for are a designed feature of the simulation rather than a defect. If designers know of the repetition test, the designers build in whatever the test is meant to detect. A designer can defeat the repetition test with pseudo-randomness: variation produced by a fixed procedure that only looks random. Pseudo-randomness is cheap to produce.

The second candidate is simultaneity. An ant colony and a stock exchange go about their business independently of each other, and throughout the universe an enormous number of processes occur at once, each seemingly unconnected to the rest. Could a single computation carry all of

the processes of the universe at once? Yes: computer engineers handle exactly the case of many simultaneous processes by parallel computation, in which many processors run at the same time. A software engineer models each independent process by an independent thread, a separate stream of instructions. The number of threads is a matter of hardware. So simultaneity, by itself, is no distinction in kind between a simulation and the world.

A related but distinct question is how much parallel computation a simulation of the universe would need. The universe contains an enormous number of processes operating simultaneously at every scale, from the quantum fluctuations of the vacuum to the gravitational interactions of galaxy clusters, and a simulation of the universe would need to compute all of those processes in parallel. Modern computers can run some processes in parallel, but modeling even a cubic centimeter of ordinary matter at quantum resolution would need more parallel processing than anything that is now conceivable. The shortfall of modern computers is a limit of practice. A limit of practice does not distinguish a simulation from reality in principle, which is the standard that Section II sets. So we must look further.

The two failures have the same form. In each case the simulation defeats the test by adding more of something the simulation already has: more designed variation, or more parallel capacity. Each test required only something that discrete logic can, in principle, supply. The failure of the two tests therefore refines the inquiry instead of ending the inquiry, because each failed candidate narrows the search toward a distinction that no amount of added discrete resource could make up.

IV. Randomness, the Division of Space, and the Planck Objection

Three further considerations show the axis along which the simulation question must be decided: randomness, the structure of space, and the binary hypothesis.

The first consideration is randomness itself. A computation operates by procedure, step by step from inputs to outputs. Even randomness in a computation must be generated by some procedure. Whatever a procedure generates is, for that reason, not random in the hard sense. In the sense of the essay on hard randomness in Part II, hard randomness is what is not the output of any algorithm. A computation can imitate hard randomness but cannot produce hard randomness. If nature contains hard randomness, then a simulation can never fully replicate the hard randomness of nature, and the simulation's imitation must bear some trace, however faint, of the procedure that made the imitation. A simulation could instead draw hard randomness from a physical process in the world that runs the simulation, but the simulation's randomness would then belong to the world that runs the simulation, carried through the computation, and not to the simulation itself. So a simulation already differs in principle from a world that contains hard randomness: the simulation can only imitate hard randomness, or carry the hard randomness of another world. I dissolved the simulation hypothesis in *Third Resolutions in Western Philosophy* by exactly the route through hard randomness: I argued through the binding of hard randomness to temporal direction and to subjectivity. I do not restate the argument from hard randomness in this essay. In this essay I come to a compatible conclusion by a different route. The two arguments are stronger together because neither depends on the other.

The second consideration is the structure of space. Continuous space can be divided without limit. Take any interval and split it, then take a half and split the half again. The geometric concept of space contains no smallest distance. But a simulation must represent space by finitely many data points, and however many points the simulation uses, there are gaps between neighboring points. A denser representation comes closer to continuity, but no density of points is continuity.

The finite grid of a simulation invites a natural objection, and the objection needs a careful answer. Physics has a scale called the Planck length, which the literature gives as roughly 1.6 times 10^{-35} meters. At the Planck length, a body's gravitational size equals the body's quantum size. At the Planck length, two descriptions exchange dominance: the description of the arena (space and time) and the description of the arena's content. People often take the Planck length for a smallest length, below which distance and duration cease to apply. Does a smallest length rescue the simulation hypothesis? If there is a smallest unit of measure, perhaps reality is already granular (already a grid), and there is no continuity left to simulate.

My first reply: the Planck length is not a smallest length. No measurement has found a least step of length at any scale yet probed. Astronomers have found that the light of distant gamma-ray bursts arrives together across very different colors (Abdo and others, 2009), so any grain of space that would slow light in proportion to the light's energy must lie below the Planck length.

My deeper reply is the step on which the whole inquiry depends. The microscopic limit, marked by Planck's constant, is a boundary of the domain of comparison: a boundary on what can be measured. I argued in the essay on hard randomness that the microscopic boundary is categorical, not merely practical: no better instrument will cross the boundary. But a boundary on measurement does not make existence granular. The Principle of Identity does not license the inference from "nothing below this scale can be compared" to "nothing below this scale exists, and what exists above it is a lattice". The Principle of Identity says that what cannot be distinguished must be regarded as the same, but the principle does not say that what cannot be measured must be regarded as discrete. The simulation question was never whether we can measure the difference between the continuous and the granular, but whether the difference exists. I examine whether the difference exists in the rest of this essay.

A second objection has the same form as the Planck objection. Two results say that a bounded region of space can hold only a finite amount of information: the Bekenstein bound, named for the physicist Jacob Bekenstein, and the holographic principle that came after the Bekenstein bound. The Bekenstein bound and the holographic principle limit what any comparison within the domain of comparison can distinguish, and a limit on what can be distinguished is a limit of the domain, not a granularity of what exists. So my reply to the two bounds is my reply to the Planck objection. The inference that the two bounds invite is the same unlicensed inference.

The third consideration is the simulation hypothesis stated explicitly. Suppose all information in the universe is representable as ones and zeros. Then one could conceive of a vast file holding the complete state of the world at one instant, as a definite and finite number of bits, and the evolution of the world would consist in the transformation of one such file into the next, according to some rule. I call the supposition that all information is representable as ones and zeros the binary hypothesis. The binary hypothesis is a hypothesis, and a clean one. Whether the binary hypothesis is true depends on a single question: is reality fundamentally smooth, or fundamentally granular? Every candidate test so far has come down to one axis: continuity against discontinuity. Observation alone cannot settle whether reality is continuous or discontinuous, and so the question requires an argument at the level of structure.

V. Two Infinities

If reality is continuous, then reality contains an unbounded amount of information that no finite representation can hold. A concrete example is the number pi, the ratio of a circle's circumference to its diameter. The decimal expansion of pi never ends and never repeats. Pi can be specified as the result of a finite algorithm applied without limit: a short program produces any digit of pi on demand, and only the program applied

without limit gives every digit. Stating pi exactly in digits would take information without bound, because no finite sequence of digits, however long, is pi. Take a physical process that depends on the true relationship between a diameter and a circumference. In a space that is continuous in fact, the process incorporates all of the information in pi. A simulation can model only finitely many digits of pi, and the simulation's approximation is not exact, however astonishingly close the approximation is.

One could reply that an approximation so close as to be beyond any measurement is as good as exact. I answer the reply in Section VI. First comes a deeper point: the gap between the continuum and any finite approximation is not a gap of quantity. The deeper point comes from two proofs by the mathematician Georg Cantor. In 1874 Cantor proved that the real numbers, the numbers that can be written as unending decimals, cannot be listed, and in 1891 Cantor gave the diagonal argument, which I present below in its usual form for decimal expansions. The general theorem of 1891 is a fact about listing: no list with one entry for each member of a collection contains every way of assigning yes or no to the members of the collection. The general theorem holds for finite collections as well as infinite ones: a collection of n members has 2 to the power n such assignments, and n is always less than 2 to the power n. The general theorem is a statement about listing, and not about the size of a completed totality. From Cantor, the framework of this book uses the fact about listing. The framework does not treat infinite totalities as completed objects of different sizes.

Two kinds of collection matter for the simulation question. The first kind is what can be listed: the counting numbers, and any collection that can be placed in one-to-one correspondence with the counting numbers. Many familiar collections can be listed: the even numbers, the primes, the squares, the rational fractions, every finite string of symbols in any finite alphabet, and every program that could ever be written. Every one of the collections can be listed because each can be set out in a systematic order that leaves nothing out.

The second kind is the space of all assignments over the counting numbers: every way of assigning yes or no to each counting number. The real line is the familiar form of the space of all assignments. No listing reaches the whole space: every list leaves out a member. No one can pair the real numbers one-to-one with the counting numbers, and the reason is structure, not want of ingenuity.

Cantor's diagonal argument shows the impossibility directly, with nothing left to interpretation. Suppose someone claims to have listed all the real numbers between zero and one, each written as an unending decimal, the first paired with one, the second with two, and so on. Now construct a new number. For the new number's first digit, choose something other than the first digit of the first number listed. At every place, never choose 0 or 9, so that the new number has only one decimal expansion. For the new number's second digit, choose something other than the second digit of the second number. Continue in the same way down the diagonal of the list. The new number differs from the first listed number in its first place, from the second in its second place, from the n-th in its n-th place, and so from every number on the list. The new number is a real number between zero and one, and the new number is not on the list. The list was therefore never complete, and no list could be complete. No listing reaches the whole of the continuum, the space of all assignments of which the real line is the familiar form.

The result that no listing reaches the continuum is Cantor's theorem. Cantor's theorem is one of the few results in this book, other than the Incommensuration Theorem, to which I give the word theorem, because Cantor's theorem is a theorem in the ordinary mathematical sense.

VI. The Consequence, and the Amplifier

Cantor's theorem has an immediate consequence for the simulation question. A computer operates with discrete, countable states. A computer's memory is a finite number of bits, and a computer's computation

is a finite number of steps. The mathematician Alan Turing described the limit of the concept of a computer, an idealized machine with unbounded time and unbounded tape, and even Turing's machine produces at every stage an output that can be listed. The totality of everything Turing's machine could ever produce can itself be listed. Suppose reality is based on the continuum, so that physical processes involve continuously valued quantities in fact and not discrete stand-ins for them. Then reality holds what no computation can reach, because a computation is a listing. A continuous universe would contain events that no one could anticipate from any prior knowledge held in discrete form, and so a simulation of the universe would diverge from the world as a matter of principle, not of practice.

Now return to the reply from Section V: an approximation too close for any measurement is as good as exact. Surely, the reply says, a simulation could carry so many digits that no discrepancy would show within the lifetime of any observer, or within the sensitivity of any instrument. The reply is correct as far as the reply goes, but the reply does not go far enough, for two reasons.

The first reason is the Principle of Identity itself, which requires only a test definable in principle. The diagonal argument describes a test definable in principle. By the diagonal argument, a continuous world carries a class of quantities that a discrete world cannot carry: the quantities that no listing reaches. A separate question is whether we can read the quantities off with our present apparatus. The philosophical point does not depend on the answer.

The second reason is physical: sensitivity to initial conditions makes the continuum argument apply to the world and not only to the concept. Real systems are, very generally, sensitive to their initial conditions: to the exact state in which each system starts. The weather is the classic case. The popular name of the phenomenon, the butterfly effect, comes from the work of the meteorologist Edward Lorenz in the early nineteen-sixties. In a system sensitive to its initial conditions, an arbitrarily small difference in the starting state does not stay small: the difference grows, and keeps

growing until the difference dominates the behavior of the whole system. So when a simulation truncates its values at any finite precision, the simulation does not merely differ from the continuum by an amount below detection. Given time, the simulation diverges from the continuous world macroscopically, on the scale of the whole system. The diagonal argument shows that the gap between the finite and the infinite is structural, and sensitivity to initial conditions converts the structural gap into a gap between two different histories, the history of the world and the history of the simulation: two different worlds. Sensitivity to initial conditions is the amplifier, and what sensitivity amplifies is what no listing reaches. When the amplifier acts, the continuous world and the simulation differ in a way that is real and in principle visible. Without the amplifier, the difference would be real but hidden.

The amplification of the structural gap is a physical claim and not only a mathematical one. I read the three-body problem as a physical instance of the same amplifying mechanism in the essay on hard randomness in Part II. In the three-body problem, three bodies come together at once and rebound. The outcome depends with extreme sensitivity on exactly how the three bodies come together, so differences below the limit of measurement are amplified into differences above the limit. Therefore the continuum argument arrives at the same mechanism as the argument from hard randomness: the amplification of differences below the limit of measurement. The diagonal argument says that some quantities cannot be encoded, and sensitivity to initial conditions says that the same quantities will eventually matter.

VII. The Continuous Wavefunction as Evidence

Up to Section VII, the continuum argument has been conditional. If reality is continuous, then no discrete computation can capture reality. For the context of every comparison, the condition (that reality is continuous) is no longer only a condition, because the continuity of context can be de-

rived, and I give the derivation next. The context of every comparison is the arena of space and time. A least step of context would be a difference of context with no sameness within the difference. Sameness and difference are inseparable, so a difference of context that contains no sameness cannot occur. So the context has no gap and no least step. Between any two settings of the context there is a third, and nothing in the context is sudden. A context with no gap and nothing sudden is continuous (*Incommensuration*, Chapter 5). The continuum argument needs exactly the continuity of context, because a discrete computation has a least step in every context the computation represents. The findings of physics agree with the continuity of context. Physicists have found the arena of space and time smooth at every scale yet probed, and the light of distant gamma-ray bursts shows that any grain of space that would slow light must lie below the Planck scale (Abdo and others, 2009). Further evidence comes from the formalism of physics: the mathematics in which the laws of physics are written.

Consider the laws of physics as we have them. Three of the laws of physics are formulated in the mathematics of the continuum: the Schrödinger equation of quantum mechanics, the field equations of general relativity, and Maxwell's equations of electricity and magnetism. Physics has so far stated the world's lawfulness as continuous lawfulness. One might propose that the continuity of the equations is an artifact of our tools: that the underlying rule is discrete, and the smooth equations are only how the discrete rule appears on a large scale. The proposal of a discrete underlying rule is exactly the binary hypothesis. The binary hypothesis has a consequence that measurement could detect.

In quantum mechanics a measured state is discrete. An observed particle is found in one place or another, and has one spin or another. But between observations the system has a probability amplitude, the quantity from which quantum mechanics calculates the probability of each outcome. The probability amplitude is a continuous function. The probability amplitude evolves continuously under the Schrödinger equation, taking on continuously varying values. The statistics of measured results depend

on the continuous evolution. Someone can choose a discrete rule that reproduces the statistics of the continuous evolution to any finite precision named in advance. But no discrete rule can be the continuous evolution itself, because the continuous evolution has no least step at any precision. The wavefunction is the probability amplitude taken as a whole. If the evolution were in fact discrete, the wavefunction would be an approximation to some one underlying finite rule. The finite rule would have a least step. With enough trials, and with enough sensitivity to reach below the least step, an experimenter would find that the statistics of the finite rule differ from the statistics of the continuous evolution. So in quantum mechanics the distinction between discrete modeling and continuous modeling is definable in principle and is also connected to a physical statistic: each proposed discrete rule fixes a precision beyond which the rule would show up in the statistics. Precision measurement and quantum information science are approaching the regime where physicists can test the statistics of a proposed discrete rule very finely.

The mathematics of the continuum is the structural foundation of quantum mechanics. The empirical success of quantum mechanics is therefore evidence that a continuous framework is needed for discrete findings, and so also evidence that what the findings are about participates in the continuum. My conclusion from the success of quantum mechanics is a reading at the level of interpretation, and the reading does not close the question, because someone could propose a sufficiently subtle discrete rule that mimics the continuous statistics to any finite precision. Against the subtle discrete rule, the argument of Sections V and VI applies again at the next level: the mimicry can be listed, the continuum cannot be listed, and sensitivity to initial conditions will eventually tell the mimicry and the continuum apart. So every discrete proposal is always one step behind the continuum, and the discrete proposal is behind in principle.

A further reading of the wavefunction belongs to this volume specifically, because the further reading uses the Incommensuration Theorem. The Introduction states the Incommensuration Theorem in full. The Incommensuration Theorem says that of the four secondary compounds of

comparison (continuity, discontinuity, symmetry and asymmetry), two conjunctions survive absolute application: continuity with asymmetry, and symmetry with discontinuity. Applied absolutely means holding exactly, at the foundation of a description. The wavefunction between observations is continuity with asymmetry: the amplitude varies smoothly, and no two points of the amplitude's evolution are identical. The measured outcome is symmetry with discontinuity: a discrete, exchange-invariant, countable result. Quantum mechanics contains the two survivors at its two levels. The first level is the continuous evolution in the formalism, which exists. The second level is the discrete outcome in the findings, which is real. The interaction called measurement is the step between the two levels: the step from the continuous evolution to the discrete outcome. A discrete simulation of the whole would require the discontinuous side to be perfected across the whole, which is to require that continuity be entirely absent. I read the continuous wavefunction as the place where physics itself does not satisfy the requirement of a discrete simulation, because continuity is present in the wavefunction.

VIII. Symmetry, Continuity, and the Self

The deepest result of this inquiry is that the distinction between what can be listed and what no listing reaches is an instance of the relationship between symmetry and continuity, the two types of law that I develop in Part I of this volume.

Symmetry is sameness of content across difference of context: invariance under transformation. The finitary, countability and existence all have an affinity with symmetry. So does everything that can be listed, shared and repeated. The digital number system embodies symmetry in its very construction, because the system is built on the exchangeable distinction between one and zero. Each bit is identical to every other bit in everything but position. A program is a finite string over a finite alphabet, and computation is the transformation of finite strings by rule. In charac-

ter, computation is symmetry with discontinuity: exchangeable symbols and discrete states, under the same rule wherever the rule runs. A theory written as a computation is laid out as structure, and in that sense the theory is purely omniscient: the structural, the repeatable and the third-person, and those things perfectly. By role, as distinct from character, computation is transcendent in the triple of physics, logic and computation: a procedure is defined over the range of the procedure's possible inputs, and each run of the procedure selects one path through the range (*Measurement*).

Continuity is sameness of content within sameness of context: the property of the real line by which every point joins smoothly to its neighbors without gap or jump. Continuity is deeper and less reducible than symmetry, in the specific sense that continuity cannot be listed. Cantor's theorem is the statement that no procedure enumerates the continuum. In the vocabulary of the Incommensuration Theorem, listing is the symmetric operation and exhaustive coverage is the continuous operation. Cantor's diagonal argument is then the prohibition of the perfected conjunction of listing with exhaustive coverage: no list can be perfect as a list and also cover the whole continuum (*Category Theory and the Immanent Metaphysics*, Chapter 17). The real line of mathematics is a mixed structure in which comparisons of both kinds occur, symmetric and continuous, but what the continuum argument needs is the continuity that the Incommensuration Theorem defines (sameness of content within sameness of context), not the continuity of the mathematician's real line. In the modal alignment of this book, continuity is transcendent. The transcendent is the mode of the self, of the subject, of choice and of possibility.

With the modal alignment the continuum argument goes beyond physics. I state the step beyond physics plainly, so that the reader can weigh the step for what the step is. Subjectivity is, at its foundation, continuity with asymmetry: the self persists without a break, and no two moments of the self are the same. Within the unbroken persistence of the self, the contents of the self vary discretely: the thoughts and perceptions. The claim that subjectivity is continuity with asymmetry is a claim of the

framework, and not a result of any experiment. The claim says that no listing could capture the first-person, because listing is a symmetric operation, and the subject is the pole of comparison at which symmetry does not reach: the side from which the comparison is made. The Incommensuration Theorem forbids the perfection of symmetry with continuity, and therefore the same theorem forbids the perfection of computation with subjectivity. A computation perfected as computation is symmetry-with-discontinuity applied absolutely. By the Incommensuration Theorem, continuity applied absolutely is excluded where symmetry-with-discontinuity is applied absolutely. Continuity applied absolutely is exactly what the self is.

I call my two independent arguments against the simulation hypothesis the two roads, and the two roads come together at the self. I argued in *Third Resolutions in Western Philosophy* that a computation cannot generate hard randomness, and that hard randomness, temporal direction and subjectivity are bound so that none can be imported without the others. In this essay I argue that a computation cannot hold the continuum, and that subjectivity is continuous. The first road runs through the immanent: interaction and what enters interaction. The second road runs through the transcendent, through what cannot be enumerated. Both roads arrive at the same place: the inside of a simulation cannot be a separate world and cannot contain a separate self. I expect both roads to arrive at the same place, because in the framework of this book the two roads are the two survivors of the same theorem, the Incommensuration Theorem, seen from opposite ends.

IX. Summary

No discrete computation can capture a continuous reality, and the exclusion is a structural exclusion. For the context of every comparison, I derive the antecedent of the exclusion (that reality is continuous), and the smoothness of the arena of space and time agrees with the derivation as

evidence. My readings in Section VII are readings of known results: the reading of the continuous wavefunction, and the reading of quantum evolution and measurement as the two survivors at the two levels of one theory. Subjectivity is, at its foundation, continuity with asymmetry, and that claim is a claim of the metaphysics itself. Discrete methods in physics are indispensable, and the continuum argument says nothing against discrete methods, because the subject of the continuum argument is difference in kind, not difference in degree.

The simulation question served as a doorway into the framework. Through the simulation question I came to the Principle of Identity, the failure of the naive tests, the mathematics of infinity, Cantor's diagonal argument, the amplifying role of sensitivity to initial conditions, and the continuity of physical law. The conclusion is strong. The context of every comparison is continuous, as the Incommensuration Theorem requires and as physics finds. So something about the nature of what exists is beyond what any computation can capture, and the difference between the world and a computation is a difference of kind, not of engineering.

The continuum argument belongs in this volume because the argument's result turned out to be an instance of the relationship between symmetry and continuity: what can be listed and what no listing reaches are symmetry and continuity seen in the mirror of mathematics. Computation is symmetry perfected. The continuum is what symmetry perfected leaves out. In the account of this book, the self lives on the side that symmetry perfected leaves out, the side of the continuum. A simulation can restrict what an observer sees. But a simulation cannot count what cannot be counted, and for that reason a simulation cannot contain a subject. In the essay that follows, I take up the same conclusion from the side of the computationalist thesis itself: the thesis that the universe is a computation.

KEY CONCEPTS IN THIS ESSAY

- **Principle of Identity**: what no conceivable test can distinguish must be regarded as the same; a consequence of what comparison is, not a physical law.
- **Test in principle**: a distinguishing test whose logic is sound whether or not any instrument can perform the test; the standard that the Principle of Identity sets.
- **Binary hypothesis**: the proposal that the complete state of the universe is a finite string of bits, evolved by rule; the strong form of the simulation hypothesis.
- **What can be listed**: any collection that can be placed in one-to-one correspondence with the counting numbers; every program and every computational output can be listed.
- **The continuum**: the space of all assignments over the counting numbers, of which the real line is the familiar form; by Cantor's theorem no listing reaches all of the continuum; the context of every comparison is continuous (*Incommensuration*, Chapter 5).
- **Cantor's diagonal argument**: the construction of a real number differing from every member of any proposed list. The diagonal argument is the argument by which Cantor showed that no listing reaches the continuum. In the vocabulary of the Incommensuration Theorem, the diagonal argument is the prohibition of perfected listing with exhaustive coverage.
- **Sensitivity to initial conditions**: the amplification of arbitrarily small differences in a system's starting state into macroscopic differences in the system's behavior; the mechanism that makes a structural gap observable.
- **Planck length**: the scale at which the description of the arena and the description of the arena's content exchange dominance; the Planck length is no least length; the microscopic limit, marked by Planck's constant, is a limit on measurement, not a granularity of existence.

- **Continuity of the subject**: subjectivity is, at its foundation, continuity with asymmetry, with discrete contents within an unbroken persistence; a claim of the metaphysics rather than of physics.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms), 1.43-6 (measurement as interaction), 1.83-1 and 1.75-13 (the two laws).

Landry, Forrest. "The Simulation Hypothesis Dissolved." In *Third Resolutions in Western Philosophy.* UVSM Publications, 2026.

Landry, Forrest. *Accessing the Real.* UVSM Publications. The essay on the binding of subjectivity, temporal direction, and hard randomness.

Cantor, Georg. "Über eine Eigenschaft des Inbegriffes aller reellen algebraischen Zahlen." *Journal für die reine und angewandte Mathematik* 77 (1874): 258–262.

Cantor, Georg. "Über eine elementare Frage der Mannigfaltigkeitslehre." *Jahresbericht der Deutschen Mathematiker-Vereinigung* 1 (1891): 75–78.

Turing, Alan M. "On Computable Numbers, with an Application to the Entscheidungsproblem." *Proceedings of the London Mathematical Society* s2-42, no. 1 (1936): 230–265.

Lorenz, Edward N. "Deterministic Nonperiodic Flow." *Journal of the Atmospheric Sciences* 20, no. 2 (1963): 130–141.

Schrödinger, Erwin. "Quantisierung als Eigenwertproblem." *Annalen der Physik* 79 (1926): 361–376.

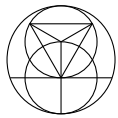
Bostrom, Nick. "Are You Living in a Computer Simulation?" *Philosophical Quarterly* 53, no. 211 (2003): 243–255.

Bekenstein, Jacob D. "Universal Upper Bound on the Entropy-to-Energy Ratio for Bounded Systems." *Physical Review D* 23 (1981): 287–298.

Abdo, A. A., et al. "A Limit on the Variation of the Speed of Light Arising from Quantum Gravity Effects." *Nature* 462 (2009): 331–334.

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3. Chapter 5 (the law of continuity for context).

Landry, Forrest. *Category Theory and the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-071-8. Chapter 17 (Cantor's theorem as an instance).



Essay 19

Against Computationalism

Non-Falsifiability, the Bound Triple, and Mind Uploading as Category Error

ABSTRACT

Computationalism is the thesis that all of physical reality is, in principle, computational: that every process can be represented as discrete operations on discrete states (separate steps, each taking one separate state to the next). Computationalism is the assumption beneath most present-day talk of mind uploading, of total simulation and of the computational nature of consciousness. Mind uploading is the proposal that a person can be captured in a computational representation. Yet people rarely state computationalism as what it is: a metaphysical thesis, a thesis about what reality is. In this essay I examine the thesis itself, not only its applications. I argue first that computationalism is non-falsifiable, because no observation could count against computationalism, and that computationalism is therefore not a scientific claim, which is a different charge from saying that computationalism is false. I then give reasons to think that computationalism is false. Computation is deterministic (each step is fixed by the step before), time-symmetric (a computation can be run backward as well as forward) and without interiority (a computation has no inside point of view). Three features of reality form what I call a bound triple: hard randomness (an outcome that nothing before it fixes, even in principle), the arrow of time (the difference between a determined past and an open future) and subjectivity (the point of view from which a com-

parison is made). Each of the three requires the other two, and computation factors out all three at once: computation removes all three together. What computation cannot represent is exactly what constitutes experience. So mind uploading is a category error, and not an engineering problem that awaits better hardware: mind uploading is the request that one mode of description do the work of another. I close with my overall impression of the Wolfram Physics Project. The Wolfram Physics Project is the scientist Stephen Wolfram's program to obtain all of physics from simple computational rules. I read the project through the conservation of information (the rule that a deduction puts out no more information than goes into it), and my impression is that the Wolfram Physics Project is an instance of purely omniscient theory, theory laid out wholly as structure. I also observe that any purely omniscient theory must leave an incompressible residue of hard randomness, which the theory can neither predict nor explain.

Note on framework. This essay depends on the Introduction to this volume for two things: the Incommensuration Theorem and the modal alignment. This essay also depends on two earlier essays in this volume, the essay on determinism and the essay on hard randomness, and on the essay on the continuum argument, which comes just before this one. This essay refers to two of my other books: to the essay in *Accessing the Real* on the binding of subjectivity, temporal direction and hard randomness, and to the essay in *Third Resolutions in Western Philosophy* that dissolves the simulation hypothesis. The argument of this essay needs nothing beyond what the Introduction and this essay state.

I. The Thesis and Its Momentum

In its strong form, computationalism is the claim that the universe is a computation. On the strong form, every physical process can in principle be represented as a sequence of discrete operations on discrete states. What exists is then, at bottom, information processing.

The strong form has sweeping consequences, and the people who hold the strong form intend the consequences to be sweeping. If the universe is a computation, then any sufficiently faithful simulation of a physical system is the same as the original system, for every purpose that matters, and so a simulated brain would be a real mind. Mind uploading would then be natural, and not merely possible, because mind uploading would follow directly from what reality already is. Digital immortality would follow too, and so would the thought that persons are, at bottom, information. Digital immortality is the survival of a person as a running program.

Computationalism has enormous cultural momentum: the thesis is widely held, and the thesis is rarely questioned. Computationalism is the metaphysical assumption behind much talk about machine intelligence, virtual worlds, the simulation hypothesis and the future of the person. The simulation hypothesis is the proposal that our world is a computation run in a more fundamental world. Computationalism is almost never argued for, and people treat computationalism as obvious, as the default position, which a scientific mind should adopt unless given some reason to reject it. Computationalism deserves to be stated plainly and examined as what it is, a metaphysical commitment, exactly because people treat computationalism as obvious. In the framework that I develop in these volumes, I reject computationalism at its root: I reject the thesis itself, and not only its applications.

In the preceding essay in this volume I came to the question whether reality is a computation from the side of the continuum, the real number line and every space like it, which no list can run through completely. I ar-

gued in the preceding essay that every computation is a listing, a sequence that can be counted off item by item, and that no computation can capture a reality that no listing reaches. In this essay I come to the same question from the side of the computationalist thesis itself: I ask what kind of claim computationalism is, and what computationalism necessarily leaves out.

II. Non-Falsifiable, Which Is Not the Same as False

A law that holds within one domain is a scientific claim, and a scientific claim must be falsifiable. When some possible observation would count against a claim, we call the claim falsifiable. Falsifiability is not the whole of what makes a claim scientific, but falsifiability is a necessary part. So a clean first question to ask is a question about falsifiability. What observation would falsify computationalism?

No observation would falsify computationalism. If a phenomenon appears non-computational, the computationalist can answer that the underlying computation is simply more complex than we have yet understood. If a process appears to involve genuine randomness, the computationalist can posit a deeper deterministic layer beneath the process. If consciousness resists simulation, the computationalist can blame the resistance on insufficient fidelity, which the next round of hardware is expected to remedy. No state of affairs would count, for the computationalist, as a refutation of computationalism. The computationalist treats every apparent counterexample as a promissory note: a promise that some future computation will account for the counterexample.

Computationalism is not a scientific conclusion, because no observation could count against computationalism. Computationalism is a metaphysical commitment presented as an empirical finding.

I state the charge precisely, because the charge is easily misheard. My claim is that computationalism is non-falsifiable, and not that computationalism is false. Computationalism therefore occupies the same epistem-

ic category (the same standing as knowledge) as any other unfalsifiable commitment, religious commitments included. Computationalism may be believed. Science cannot establish computationalism, and no one may claim the authority of science for computationalism. In an earlier essay in this volume, the essay on what physics cannot reach, I argued that falsifiability applies to claims of how and why, and not to claims of what. I argued there also that to treat a metaphysics as falsifiable is a category error. A category error is the mistake of applying a concept in a domain where the concept does not belong. In this essay I apply the same point in the other direction, to computationalism. Computationalism is a metaphysics, and a single observation does not refute a metaphysics the way a single observation refutes a law. A metaphysics is judged by argument. Where the consequences of a metaphysics are claims about physics, experiment judges those consequences. In the rest of this essay I give the argument against computationalism. The conclusion of the argument is that computationalism is false as a matter of structure.

III. What Computation Is

The whole of the argument against computationalism depends on three features of computation, and none of the three features is controversial. Computation is deterministic, computation has no direction of its own, and computation is without interiority.

Computation is deterministic. A Turing machine is the standard model of computation: the imagined machine that the mathematician Alan Turing described. A Turing machine has a state, a tape, and a transition function: the state is the machine's current setting, the tape is a strip of cells that each hold one symbol, and the transition function is the rule for what the machine does next. When the current state and the current symbol are given, the transition function uniquely determines what the machine does next: the next state, the symbol to write, and the direction to move. Each step of a Turing machine is free of ambiguity and free of indeterminacy.

Software is also made of states, conditionals and loops, and in software every step is fixed by the step before. Computation is reliable, verifiable and reproducible because every step is fixed by the step before. Every computation can be expressed as a deterministic sequence of state transitions. A pseudo-random number generator is a program whose outputs pass every statistical test of randomness, while the outputs are fully determined by the generator's seed, the number the program starts from. No computation produces hard randomness. A computation can only imitate hard randomness.

The obvious objection is that a computer can read a quantum random-number source, a device that produces numbers from quantum measurements. But randomness read from a physical device enters the computation as input from outside the computation. Input from outside is the entrance of information that I describe in the essay on the microscopic boundary. The microscopic boundary is a domain's limit at the small end. The computation itself remains deterministic, because the randomness is in the physics of the device and not in the algorithm, so the randomness of a computer that reads a quantum source is the world's randomness, carried through the computation. A computer's direction of time follows the computer's randomness. So a computer that reads a quantum source has the world's direction of time too. Section IV sets out the bound triple: hard randomness, the arrow of time and subjectivity, each requiring the other two. The bound triple cannot be carried across in part, from the world into a computer: where the randomness and the direction of time are shared, the subjectivity is shared as well. A quantum computer is a case of the same kind. Between preparation and readout, the operations of a quantum computer are a reversible rule. A quantum computer's readout is a measurement made in the world. So whatever share of the bound triple a quantum computer has, the quantum computer has that share at its measurements, as a physical system, and never by virtue of the program it runs.

Computation has no direction of its own, because every computation can be carried out reversibly, by keeping a record of each step, and the reversed computation is itself a computation, as the physicist Charles Bennett showed (Bennett, 1973). Where an actual computer does have a direction, the computer has the direction because the computer erases information. The physicist Rolf Landauer showed that erasure is a thermodynamic act of the physical machine, and not a feature of the computation (Landauer, 1961). So the direction of an actual computer comes from the substrate and the clock, and never from the algorithm. The substrate is the physical material that carries out the computation. If a computation appears to have a temporal direction, something outside the computation imposes that direction, whether the hardware clock, the intention of the programmer or the order in which someone chose to read the tape. A deterministic sequence has an ordering (step one then step two then step three), but an ordering is not a direction. An ordering can be read either way, forward or backward, with no structural difference between the two readings.

Computation is without interiority. A Turing machine has no perspective. There is nothing it is like to be a transition function: a transition function has no experience of its own. The description of a computation is complete from the outside, in the third person, and a first-person report adds nothing to the description of a computation, because a computation has no first person to make a report. The lack of a first person is no limitation of present machines. The concept of computation is the fully specified, fully shareable, fully repeatable transformation of symbols. A fully specified transformation of symbols has no first person.

In the modal alignment fixed for this book in the Introduction, symmetry is omniscient, continuity is transcendent and interaction is immanent. The omniscient is the mode of structure. In the modal alignment, the three features of computation (determinism, no direction of its own, no interiority) say one thing. In character, computation is purely structural and so purely omniscient: computation is the repeatable and the third-person, existence and pattern and law with nothing else admitted. Two

modalities are absent from computation: the immanent, which is the here and now of interaction and change, and the transcendent, which is the evaluative and the possible. The absence is no accident, because computation is defined by excluding the immanent and the transcendent.

IV. The Bound Triple

The substantive argument against computationalism depends on a single structural observation. I develop the observation at length in my book *Accessing the Real*, and I use the observation throughout this volume. Hard randomness, the arrow of time and subjectivity are three features of reality, and together the three features form a bound triple. The three features are inseparable: removing any one of the three removes the other two as well. I derive the binding of the three features from the Incommensuration Theorem. Then I show that the findings of physics bear the binding out.

The binding follows from the Incommensuration Theorem. The Incommensuration Theorem says that symmetry and continuity cannot both be perfected in one description of one thing. Every comparison leaves a remainder, because symmetry and continuity cannot both be perfected, and the remainder, which is an outcome that prior structure does not fully determine, is hard randomness. Every comparison is made from a stance, the subjective pole of comparison, and the stance is subjectivity. Every comparison also proceeds in a direction, from the act of comparing to the record of the act. The direction is the arrow of time. Hard randomness, subjectivity and the arrow are three aspects of one structural act: a comparison that proceeds in a direction, is registered by a perspective, and has an outcome not fully determined. None of the three aspects is present without the other two.

An interpretation of quantum mechanics is an account of what the equations of quantum mechanics say about the world. Physics bears the binding out in the two most opposed interpretations of quantum mechan-

ics: the Copenhagen and the many-worlds interpretations. The Copenhagen interpretation keeps the observer, the random single outcome and the irreversibility of measurement. In the many-worlds interpretation, every possible outcome of a measurement happens, each on its own branch of the world. The many-worlds interpretation drops all three at once, because the many-worlds interpretation has no fact of which branch a comparer is in, no outcome that is not fixed, and a fundamental equation that is symmetric in time. So each of the two interpretations keeps the three features together or drops the three features together. The binding of the three is therefore established twice: derived from the Incommensuration Theorem, and found in physics.

Hard randomness is genuine ontological indeterminacy: an irreducible openness in what happens next, in the events themselves, and not the unpredictability of ignorance that better knowledge of the initial conditions could resolve. Quantum measurement is the clearest case of hard randomness. In the essay on hard randomness in Part II, I gave the reasons for taking hard randomness to be a feature of nature, rather than the effect of a deeper order that is hidden from us. The reasons come from Bell's theorem, proved by the physicist John Bell, and from the loophole-closing experiments that tested Bell's theorem.

The arrow of time is the structural fact that the past is determined and the future is open. In the essay on the structural arrow of time in Part III, I argued that the structural arrow is prior to the thermodynamic arrow. The thermodynamic arrow is the direction in which disorder grows. Genuine openness requires hard randomness, and the arrow requires genuine openness. Without openness there is no arrow, only an ordering that could be read either way.

Subjectivity is the subjective pole of comparison, the stance from which every comparison is made. In a conscious being, subjectivity is the fact that there is something it is like to be that being (Nagel, 1974). The phrase "something it is like" is from the philosopher Thomas Nagel. The hard problem of consciousness is the question why there is experience at all, rather than information processing with no one to whom the pro-

cessing happens. At bottom, the hard problem is the observation that no structure handed to another person contains one's own knowing. A complete description of pain is knowledge laid out as structure, and what pain feels like is known only in one's own perceiving. The explanatory gap is the gap between physical description and conscious experience. The explanatory gap is a structural feature of comparison itself. Subjectivity is the interior face of the very asymmetry that the arrow of time names: subjectivity is the perspective from which what has been determined is told apart from what has not been determined.

The binding of hard randomness, the arrow of time and subjectivity is seen most clearly through the distinction of content and context, the distinction that grounds the metaphysics of comparison. In a comparison, the content is the respect being judged, and the context is the respect that makes the two compared things two. Hard randomness is the entrance of novelty: content arriving that no prior context contained. The arrow of time is the asymmetry between what has been determined and what has not, the difference between the context that is closed and the content that is still open. Subjectivity is the interior perspective on the asymmetry between the determined and the undetermined: the point from which the open is seen as open. Hard randomness, the arrow and subjectivity are three faces of one structure. One cannot have a face without the solid whose face it is, so none of the three exists apart from the one structure.

Suppose first that hard randomness is removed. Then every event is fixed by prior states, the future is as determined as the past, and the distinction between past and future becomes one of perspective and not of being. Subjectivity is the capacity for genuine choice, and subjectivity then has nothing left to choose. Suppose next that the arrow of time is removed. Then cause and effect are interchangeable, and a random event, which is an event not fixed by its causal history, has no causal history to be free of. Experience is intrinsically temporal, so without the arrow experience has no medium. Suppose last that subjectivity is removed. A choice and a random event look alike from outside in any case, and without subjectivity the distinction between the two loses the one vantage from which

the distinction had content. And the arrow of time is then a statistical artifact, because the arrow has no interior for which to be an arrow. So each of the three requires the other two.

Each of the three also requires the next, and the three requirements close a circle. Directed time requires hard randomness. If every state were fixed by the states before it, the future would be contained in the present as fully as the past is, and the order of states would be an indexing, a numbering of the states, and not a direction of process. Hard randomness requires subjectivity. A purely third-person description cannot tell an outcome that no prior state fixed from an outcome that was fixed and is unknown, because neither outcome was predicted. The difference between the two outcomes is the difference between a finding that is new and a finding that was only hidden, and a finding is made by a comparer, from a stance. Subjectivity requires directed time. A stance sets what is found against what was found. Remembering sets the present against a record, and anticipating sets the present against what could come. Remembering and anticipating each run one way. Without a direction of time, remembering and anticipating would not differ, and there would be no side to look from.

V. What Computation Factors Out

The argument against computationalism can now be stated in one step. Computation is deterministic, time-symmetric, and without interiority. The bound triple is hard randomness, directed time, and subjectivity. Computation removes all three, and computation removes the three as a single act rather than one at a time, because the three are one structure and computation is defined as the absence of that structure. Therefore computation cannot replicate any system in which the three are present. The systems in which the three are present are the systems that are real in the full sense.

The argument would go through even if computation removed only one of the three, because by the binding the other two would go with the one removed. The conclusion does not need computation to remove all three directly. Computation does remove all three directly, and the direct removal shows how different the two modes of description are: the computational description, and the description of a system in which the three are present.

I make one more point about the subjective and the random, because the relation between the subjective and the random is where readers most often misread the argument against computationalism. From the outside, a conscious choice is indistinguishable from a random event. If I raise my left hand rather than my right, and if the choice is genuine, not fixed by prior states, then from any external vantage my choice looks exactly like randomness. No external measurement can tell my choice apart from a random event, and the reason is that my choice and the random event are the same event, described from two modal positions. From the omniscient position, the position of structural law and third-person description, the undetermined outcome is hard randomness: a gap in the specification, and a gap without pattern and without meaning. From the transcendent position, the position of the person engaged, the same outcome is a choice that is meaningful to the process from which the outcome came. Neither description can replace the other. From outside, the outcome is randomness, and from inside, the outcome is choice: one event has two descriptions, both correct and neither complete. From outside, choice and hard randomness are isomorphic (the same in form) in a precise sense: no external measurement can tell the two apart.

In the framework of these volumes I make a stronger claim than the isomorphism from outside, and I mark the claim as stronger. The stronger claim is that the subjective and total entanglement are strict isomorphs: subjectivity is the interior face of a process that, from the exterior, presents as entanglement and hard randomness. Entanglement is the quantum linking of two or more systems into one shared state. On the account of these volumes, the brain operates near criticality, a regime in which small

perturbations cascade. The neuroscientists John Beggs and Dietmar Plenz studied neuronal avalanches, cascades of activity among nerve cells. The study of Beggs and Plenz suggests that the brain operates near criticality (Beggs and Plenz, 2003). Near criticality, indeterminacy at the microscopic scale enters causal chains that extend to the macroscopic scale and bear on choice. At the mesoscopic scale, between the microscopic and the macroscopic, the behavior of a brain can be modeled by approximately deterministic computation, and the model is useful. But a single choice made near criticality carries indeterminacy from the microscopic scale, and no approximately deterministic model fixes that indeterminacy. Subjectivity is a constitutive feature of the act of comparison, and so subjectivity is no epiphenomenon, no mere by-product without effects of its own.

My argument should be kept distinct from the Orchestrated Objective Reduction hypothesis (Hameroff and Penrose, 1996). The hypothesis is the work of the physician Stuart Hameroff and the physicist Roger Penrose. The Orchestrated Objective Reduction hypothesis locates consciousness in sustained quantum coherence in a specific biological structure. The hypothesis faces a standard objection, made by the physicist Max Tegmark: entanglement in warm neural tissue decoheres (loses its quantum character into the surroundings) far too quickly to bear on neural events (Tegmark, 2000). The Immanent Metaphysics, the framework of these volumes, does not depend on any specific biological mechanism. The Immanent Metaphysics needs no sustained entanglement in the brain. The claim of the Immanent Metaphysics is a claim about the relationship between interior and exterior perspectives, and the claim holds for any system in which novelty enters, time is directed, and there is a point of view. The criticality of the brain is the physical circumstance under which the relationship between interior and exterior is expressed in us, and the criticality of the brain is not the relationship itself.

Nothing in the argument of this essay diminishes computation. Computation is enormously powerful. Machines built on computation can be made to do a great many things that once required a person. Machines will be made to do more. The boundary that I draw in the argument lies

between processing and experience, and not between the stupid and the intelligent. In the sense of competence at a task, intelligence is an omniscient property: structural, repeatable, shareable and assessable from outside. Experience is not an omniscient property. So intelligence remains entirely open to computation, and only experience is closed to computation.

VI. Mind Uploading as Category Error

If the bound triple is correct, then mind uploading is not a difficult engineering problem. Mind uploading is a category error, and the difference between an engineering problem and a category error is the central claim of this essay.

An engineering problem is a problem whose goal is well-formed and whose obstacle is resource: speed, memory, resolution, fidelity, time. The history of computing is a history of engineering problems of this kind being solved, so it is natural to suppose that the simulation of a mind is one more engineering problem, harder than the rest but of the same kind. The supposition is that a person is, at bottom, information, that a sufficiently complete scan of the person would capture everything relevant, and that a sufficiently faithful execution of the scan would be the person.

A category error is a different kind of difficulty. A category error is the mistake of applying a concept from one domain to another domain where the concept does not belong, so that a request built on the concept is malformed rather than hard. To upload a mind is to require that every relevant feature of a conscious system be captured in a computational representation. But three features constitute the irreducible conditions of experience: the entrance of novelty, the direction of time, and the interior point of view. The three conditions are exactly the features that computation cannot represent. The three conditions are structural absences in computation, not difficulties for computation. Computation is what you have when the three conditions are factored out. If you ask a computation to

contain the three conditions, you ask for a description that is at once complete from the outside and possessed of an inside, at once fully determined and open, at once reversible and directed.

The same point can be stated in terms of the Incommensuration Theorem. A classical computation is one rule applied the same way at every step, which is symmetry perfected. What is absolutely symmetric is intrinsically discontinuous. So computation, perfected as computation, is symmetry with discontinuity applied absolutely. The first-person stance is continuity with asymmetry: an unbroken engagement that runs one way and sets this moment apart from every other. A continuity cannot be composed of purely symmetric steps, as a curve cannot be composed of tiles, however small the tiles are made. The Incommensuration Theorem forbids the perfection of symmetry with continuity, and therefore the theorem forbids the perfection of computation with subjectivity. A person is not a very large file. A person is what a file, by its nature, is not: a first-person stance that is continuous and directed.

On this argument, a computational system can still be built to behave as a person behaves, to any degree of behavioral fidelity one likes. Behavior is exterior, and the exterior is omniscient, and there is no structural bar to an omniscient description of the omniscient. I argue that a computational system built to behave as a person behaves would not be that person, or any person, because exterior description does not exhaust what it is to be a person. The dream of digital immortality rests on assuming that persons are information. The bound triple says that persons at bottom are the conjunction of genuine novelty, irreversible time and interior experience. Information, by itself, cannot be the conjunction of the three.

The simulation hypothesis is the proposal that our world is a computation run in a more fundamental world. A deterministic computation contains no hard randomness of its own, so a simulated world draws its randomness from one of two places: from a pseudo-random generator, or from a physical source in the world that runs the computation. If the randomness of a simulated world is pseudo-random, the simulated world has an indexing of states and no arrow of time. So, by the bound triple, the

simulated world has no subjectivity: the simulation is a program running on a machine with no one in it. If the randomness of a simulated world is drawn from a physical source in the world that runs the computation, then the simulated world's randomness is the randomness of the world that runs the computation. The simulated world's arrow of time then follows the shared randomness. The simulated world's subjectivity is shared as well, since the bound triple cannot be carried across in part. Therefore a simulated world containing real subjects is a restricted region of the one world in which the simulation runs. The simulated world is not a separate world. The philosopher Nick Bostrom gave a probabilistic argument for the simulation hypothesis (Bostrom, 2003). Bostrom's argument counts each simulated world as a separate world with its own observers, and the bound triple shows that the step of counting each simulated world as separate is wrong. The argument about the simulated world is one end of a structure, and the argument about mind uploading is the other end of the same structure. In the argument about the simulated world, the world could not be put inside a computation, and in the argument about mind uploading, the person cannot be put inside a computation.

VII. The Wolfram Physics Project: An Impression

I close with a concrete instance of the computationalist thesis in its most ambitious scientific form, and I offer what follows about the Wolfram Physics Project as my overall impression, and not as a verdict. In the Wolfram Physics Project, Stephen Wolfram and his colleagues propose to obtain all observable phenomena from simple computational rules applied to initial conditions. Overall, the project seems to me to be purely omniscient theory. As purely omniscient theory, the project seems to me inherently unable to ask or answer what are probably the most interesting and deepest questions. Purely omniscient theory is theory laid out wholly as structure, which admits only what is structural, repeatable and third-person.

The model behind the project can be stated in general terms. One begins from observations of the form "rule structure X and initial condition Y lead to complicated state Z," and from observations of that form one is tempted to infer two things about observation and about science. The first inference is that every complex observation Q could itself be the outcome of some special selection of X and Y. The second inference is that the task of science is merely to find which X and Y produce outcomes resembling Q. The two inferences, generalized, are what make a theory of everything. Near as I can tell, the research program of the project is the search for the X and Y that produce outcomes resembling Q, and the rest of the project fits into that research program.

I examine the research program in terms of information. Does the complicated state Z carry any more information than X and Y together? Insofar as Z is the deterministic result of X and Y alone, with nothing from outside added, the information content of Z cannot exceed the information content of X and Y. The conservation of information under deduction is inherent in the idea of mathematics itself. If information were not conserved under deduction, the notion of a valid inference would be inconsistent. So, insofar as the notion of a theory is well-defined, the output Z carries no more information than its sources X and Y together: $I(Z) \leq I(X) + I(Y)$. In the inequality, $I(Z)$ is the length of the shortest description of Z, which is called the algorithmic information content of Z. The number of steps run is counted as part of the initial conditions Y. The inequality holds up to a constant fixed by the choice of description language.

The inequality is what makes theory useful. For some Q sufficiently close to Z, a large apparent information content is compressed to the much simpler structures X and Y, and complex, unknowable things are replaced by simpler, knowable ones. When one X is the shared basis for many Z that are close to observed Q, we call that X a law of nature. A law of nature is the best available compression of everything observed. A theory of everything is the claim that a single X, with varying Y, compresses every Q there is.

Three questions follow, and I do not think that the three questions can be answered within the research program. First: how closely must Z match Q before we may say that Q is itself actually based on some analogue of X and Y, rather than merely resembling the output of X and Y? Second: even where a Z resembles a Q, there are endless available choices of X and Y, so on what basis do we hold that the resemblance is anything other than selected after the fact? Third: even if some small set of X accounts reasonably well for a wide range of Q, where does the information in that X come from?

The third question is the deep one, and the third question is the one that any purely omniscient theory must leave unanswered. The basic problem with all purely omniscient theory is that there is always some class of information that is wholly incompressible: a just-so story, a belief, a starting point that the builders of the theory put in rather than derive. However many rounds of theory-building are attempted, and however much more arbitrary each round grows as the unmatched Q dwindle, an incompressible residue of hard randomness remains: something not predictable on the basis of any theory. Information compression can never be perfect: perfect compression would reduce all observable information to zero bits. As a program, perfected determinism is unsupportable except in terms of its absolute opposite: perfected nondeterminism, which is pure randomness. Pure randomness is an abstraction, as determinism is. The Incommensuration Theorem forbids both poles: determinism would perfect symmetry with continuity, and pure randomness would perfect asymmetry with discontinuity. Between the two poles, every actual world has causation together with a residual that no theory compresses, and the residual is hard randomness. In the essay on determinism in Part I, I gave the structural reason why no actual world is at the pole of determinism: determinism requires perfected symmetry and perfected continuity together, and the Incommensuration Theorem forbids the conjunction. The argument from information is the same exclusion of determinism, seen from the side of theory. At some level, theory must resolve to practice, and practice is inherently different from theory, even where by theory practice

and theory should be the same. At best, the third question remains unanswered and is recognized as unanswerable: the question where the information in X comes from.

Two structural grounds bear on any research program in which the world is taken to be, at its foundation, a computation. The first ground is determinism. A purely computational universe would be deterministic, and determinism needs two things, which the Incommensuration Theorem forbids together. Determinism needs the same law carrying every state into its successor everywhere and at every time, which is symmetry perfected. Determinism also needs every state specified at every point without a gap, which is continuity perfected. The second ground is the relation between a description and the thing the description describes. Every exact theory has two levels, its formalism and its findings. The formalism is the theory's equations and rules, and the findings are what is found by comparing the theory with the world. The two levels take the two surviving characters one each: each level has the character of one of the two survivors of the Incommensuration Theorem, continuity with asymmetry or symmetry with discontinuity. Consider a world computed at its foundation: a set of discrete elements rewritten by one rule applied the same way everywhere. A world computed at its foundation would have one character at both levels. One character at both levels is a character compared with itself. A comparison of a character with itself produces no finding that the character did not already hold. A computation on discrete elements can approximate smooth physics, as the grids used to forecast the weather do. The computation is then a tool used to describe the world, and not the world's foundation.

The two grounds join the bound triple of Sections IV and V to make three grounds, and from all three the same conclusion follows: the world is not, at its foundation, a computation. The premises of the three are different from one another: the Incommensuration Theorem, the two levels of every exact description, and the binding of hard randomness, the arrow of time and subjectivity. So three routes on different premises give one

conclusion, and the three routes confirm one another. None of the three routes depends on what experiments can presently detect. Each route depends on what a computation is.

The three routes depend on an order of depth among four disciplines, from the deepest to the least deep: metaphysics, physics, computation, mathematics. In the order of depth, depth is the order of presupposition. When a second discipline cannot be carried out, stated or checked without a first discipline, and the first can be carried out without the second, the first discipline is deeper than the second. Physics is deeper than computation, because every computation that is carried out is a physical process, and physics needs no computation to happen. In my book *Measurement* I give the same reason: "Computation without physics would be procedure with no substrate, since every computation that is carried out is a physical process, in circuits, in neurons or in ink" (*Measurement; The Steps from Comparison to Physics*, Chapter 14, Section XI). A rule that is never run computes nothing, and running a rule is an interaction in the world. In the same sense of depth, computation is more basic than mathematics, because every proof is checked by a computation, and no computation needs a proof in order to be carried out. Metaphysics is first in the order, because every finding of physics is an act of comparison made from inside the world, and the act of comparison presupposes none of the other three disciplines. In my book *Physics Is Not Math* I argue each step of the order of depth in full (Part Two, "The Order of the Four", Chapters 5 to 11).

Personally, I think that the drive to have things be nice and neat distorts the selection of the single X to too large a degree. Social and psychological factors matter more to the definition of science than is usually accounted for, and the negotiation among scientists of what X is can be more a matter of position than of fact. I am also skeptical that even very good matchings between Z and Q show that we understand Q. There will be other Q that do not match so well. It is not always clear that different Q belong to one class. And the state space of Q's variations can depend sensitively on factors wholly unknown. The state space of Q's variations is the range of all the ways in which Q can vary. The evolution of Q is often

highly non-linear: small changes can grow into large ones. And microscopic perturbations can introduce new information into the system everywhere at once. Determinism is distinct from causation, and hence determinism is not a good modeling basis for the larger part of actual process.

My overall impression is therefore that the Wolfram Physics Project is being oversold, and that some displaced disappointment lies in the project's future. The explanatory power of the project will forever seem just around the corner, about to arrive: hauntingly suggestive and finally unsatisfying. The Z that look like some Q are the flowers of the project, and the flowers are distracting. The flowers are all the more distracting because the question of how anything is known at all is left unresolved. The topic is physics, so the question of knowing becomes a question about physics: do we know things by experiment and observation, first person and immanent, or only by static calculation, third person and omniscient? In either case, three things are inseparable, and the three things are the bound triple again: the entrance of hard random information, the particular moment in which the information enters, and the subjective standpoint from which the entrance is even potentially observable as having actually occurred. The bound triple is forever beyond what anyone can know by a purely omniscient theory.

VIII. Summary

The argument that computationalism is non-falsifiable is a claim about the kind of thesis that computationalism is. I read computation as purely structural in character, and I read pseudo-randomness as imitation rather than production of hard randomness. Both readings are readings of known features of computation. Three claims of this essay are structural exclusions, claims that something cannot be, as a matter of structure. The three exclusions are that no computation can replicate a system in which the bound triple is present, that mind uploading is therefore excluded,

and that any purely omniscient theory must leave an incompressible residue. The three exclusions rest on the binding of the triple and on the Incommensuration Theorem. The three grounds against the thesis are independent routes to one conclusion: determinism, the two levels of every exact description, and the bound triple. The order of depth beneath the three grounds is a claim of the metaphysics itself, and in the order of depth physics is deeper than computation, because every computation carried out is a physical process. In this essay I propose no positive theory of consciousness. I establish a negative result, and I name consciousness as the bound triple taken as one act.

Computationalism is wrong in the way a category error is wrong, and not in the way a scientific theory is wrong. The computationalist takes one mode of description, computation, and asks computation to do the work of another mode entirely. Computation is deterministic, time-symmetric, and without interiority.

Hard randomness, the arrow of time and subjectivity distinguish a world where things actually happen from a world where things merely appear to happen. So the bound triple of the three is the signature of the real. If you factor out hard randomness, you have factored out the arrow of time, and with the arrow of time any possible subject. Computation factors out all three. What remains may be extraordinarily useful, and is useful, but what remains is neither reality nor a person. The gap between computation and reality is a matter of kind and not a matter of degree, so the gap will not close with any increase in computing power, any refinement of algorithm or any breakthrough in hardware.

KEY CONCEPTS IN THIS ESSAY

- **Computationalism**: the metaphysical thesis that all of physical reality is, in principle, computational; discrete operations on discrete states.
- **Non-falsifiability**: the property of a claim for which no possible observation would count as refutation; such a claim may be believed but cannot be established by science.

- **Hard randomness**: genuine ontological indeterminacy with no underlying deterministic account, even in principle; what no computation can produce.
- **Arrow of time**: the structural asymmetry between a determined past and an open future; prior to the thermodynamic arrow.
- **Subjectivity**: the first-person pole; the interior perspective on the asymmetry the arrow names.
- **Bound triple**: hard randomness, the arrow of time, and subjectivity, each requiring the other two; three faces of one structure.
- **Purely omniscient theory**: theory laid out wholly as structure, admitting only the structural, repeatable, third-person; computation, in character, is the clearest instance of purely omniscient theory.
- **Category error**: applying a concept from one domain in another where it does not belong, so that a request is malformed rather than hard.
- **Mind uploading**: the proposal that a person can be captured in a computational representation; read in this essay as a category error, not an engineering problem.
- **Incompressible residue**: the class of information that no theory can compress to fewer bits; the hard randomness every purely omniscient theory must leave unaccounted for.
- **Information conservation**: the condition that the deterministic output of a rule and of the rule's initial conditions carries no more information than the rule and the initial conditions carry together. In symbols, $I(Z) \leq I(X) + I(Y)$.
- **Order of depth**: metaphysics, physics, computation, mathematics; one discipline is deeper than another when the second cannot be carried out, stated or checked without the first, and the first can be carried out without the second; physics is deeper than computation because every computation carried out is a physical process, and physics needs no computation to happen.

Materials Reviewed

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number. Aphorisms 1.3-1 (the three axioms), 1.85-4 (causality, change, choice), 1.83-1 and 1.75-13 (the two laws).

Landry, Forrest. *Accessing the Real.* UVSM Publications. The essay on the binding of subjectivity, temporal direction, and hard randomness.

Landry, Forrest. "The Simulation Hypothesis Dissolved." In *Third Resolutions in Western Philosophy.* UVSM Publications, 2026.

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0. Chapter 14, Section XI (physics, logic and computation as one triple; computation without physics as procedure with no substrate).

Landry, Forrest. *Physics Is Not Math; Metaphysics, Physics, Computation and Mathematics, and Why Their Order Cannot Be Otherwise.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-070-1. Part Two, "The Order of the Four", Chapters 5 to 11 (the order of depth).

Bennett, Charles H. "Logical Reversibility of Computation." *IBM Journal of Research and Development* 17, no. 6 (1973): 525–532.

Landauer, Rolf. "Irreversibility and Heat Generation in the Computing Process." *IBM Journal of Research and Development* 5, no. 3 (1961): 183–191.

Beggs, John M., and Dietmar Plenz. "Neuronal Avalanches in Neocortical Circuits." *Journal of Neuroscience* 23, no. 35 (2003): 11167–11177.

Wolfram, Stephen. *A Project to Find the Fundamental Theory of Physics.* Wolfram Media, 2020.

Turing, Alan M. "On Computable Numbers, with an Application to the Entscheidungsproblem." *Proceedings of the London Mathematical Society* s2-42, no. 1 (1936): 230–265.

Bell, John S. "On the Einstein Podolsky Rosen Paradox." *Physics* 1, no. 3 (1964): 195–200.

Aspect, Alain, Jean Dalibard, and Gérard Roger. "Experimental Test of Bell's Inequalities Using Time-Varying Analyzers." *Physical Review Letters* 49, no. 25 (1982): 1804–1807.

Nagel, Thomas. "What Is It Like to Be a Bat?" *The Philosophical Review* 83, no. 4 (1974): 435–450.

Bostrom, Nick. "Are You Living in a Computer Simulation?" *Philosophical Quarterly* 53, no. 211 (2003): 243–255.

Hameroff, Stuart, and Roger Penrose. "Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness." *Mathematics and Computers in Simulation* 40 (1996): 453–480.

Tegmark, Max. "Importance of Quantum Decoherence in Brain Processes." *Physical Review E* 61 (2000): 4194–4206.

Afterword

Nineteen essays and an introduction have argued one thing from many sides.

What has been done is a reading of physics from a single structural result. The Introduction fixed the terms: comparison and its six intrinsics, the four secondary compounds, the theorem and its two surviving conjunctions, the three axioms the theorem entails, and the alignment, in the focus of the two laws, of symmetry with the omniscient and continuity with the transcendent. Part I set out the two types of law and what measurement is. Part II read four standing results as instances: Bell's theorem, hard randomness, the reach of the question *why*, and the wave and the particle. Part III went a step further and made exclusions: no superdeterminism, no signal across the boundary, no faithful reversal of time, no single theory that finds both survivors of the theorem perfected. Part IV traced the boundaries of what physics can reach, and Part V turned the same result against computation and the claim that a continuous reality could be discrete underneath.

Each essay ends with a Summary that says what kind of claim it makes. The readings are readings: the claim in each is that a known result holds for the structural reason named, and the reader can test that against the result. The exclusions are exclusions: each says what will not be found, and each is a consequence of the structure of comparison that reaches into physics, where an experiment can speak to it. No number is derived in this book, and nothing here is a physics in competition with the physics that exists. The framework does not replace the theories of physics that I read in the terms of the framework. With the framework I say why the theories of physics are shaped as they are. I also say why the effort to make the theories of physics into one theory has the character of an effort to perfect symmetry and continuity together.

This book is the companion of the books of derivation, and two things it leans on are argued in full there. The correspondence between the six intrinsics of comparison and the six measures is argued member by member in *Comparison; The Necessary Basis*, with the count, six, derived as three roles taken twice, as content and as context. And gravity as context is reached by routes that do not pass through the grid of the six measures at all: by the four markers any context must carry, in *Measurement; The Steps from Comparison to Physics*; by the law of continuity for all that is of context, in *Incommensuration; The Theorem and the Three Axioms*; and by the arena factor of the product geometry, in *Non-Commutative Geometry and the Immanent Metaphysics*. The form of the physical world, its algebra, its symmetries and its charges, is derived in that last volume; the values remain values of this universe.

In this book I have done what I set out to do, which was to place physics at the boundary of comparison and to show that the boundary explains more than the boundary obstructs. What is beyond the boundary is beyond the book.

Bibliography

One entry is given for each work cited in the essays. The aphorisms and chapters each essay draws on are listed in its own Materials Reviewed.

Works by the Author

Landry, Forrest. *Comparison; The Necessary Basis.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-062-6.

Landry, Forrest. *Incommensuration; The Theorem and the Three Axioms.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-063-3.

Landry, Forrest. *Measurement; The Steps from Comparison to Physics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-064-0.

Landry, Forrest. *Category Theory and the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-071-8.

Landry, Forrest. *Non-Commutative Geometry and the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-100-5.

Landry, Forrest. *The Quantum Passage; Quantum Mechanics from the Structure of Comparison.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-073-2.

Landry, Forrest. *The Gravitational Passage; Deriving General Relativity from the Immanent Metaphysics.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-056-5.

Landry, Forrest. *The Unquantized Arena; A Structural Diagnosis of Quantum Gravity and the Measurement Problem.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-067-1.

Landry, Forrest. *The Story of the Particles.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-053-4.

Landry, Forrest. *The Kinds of Particle.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-060-2.

Landry, Forrest. *The Strengths of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-115-9.

Landry, Forrest. *The Measures of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-116-6.

Landry, Forrest. *The Branches of the Kinds.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-077-0.

Landry, Forrest. *Physics Is Not Math; Metaphysics, Physics, Computation and Mathematics, and Why Their Order Cannot Be Otherwise.* Wytheville, Virginia: UVSM Publications, 2026. ISBN 979-8-90710-070-1.

Landry, Forrest. *An Immanent Metaphysics.* First published 2001. Wytheville, Virginia: UVSM Publications. ISBN 979-8-9896628-4-5. Cited by aphorism number.

Landry, Forrest. "The Simulation Hypothesis Dissolved." In *Third Resolutions in Western Philosophy.* Wytheville, Virginia: UVSM Publications, 2026.

Landry, Forrest. *Third Resolutions in Western Philosophy.* Wytheville, Virginia: UVSM Publications, 2026.

Landry, Forrest. *Unlocking Reality.* Wytheville, Virginia: UVSM Publications.

Landry, Forrest. *Accessing the Real.* Wytheville, Virginia: UVSM Publications.

Landry, Forrest. *The Structure of Effective Choice.* Wytheville, Virginia: UVSM Publications.

Works by Other Authors

Abdo, A. A., et al. "A Limit on the Variation of the Speed of Light Arising from Quantum Gravity Effects." *Nature* 462 (2009): 331–334.

Albert, David Z. *Time and Chance.* Cambridge, MA: Harvard University Press, 2000.

Aspect, Alain, Jean Dalibard, and Gérard Roger. "Experimental Test of Bell's Inequalities Using Time-Varying Analyzers." *Physical Review Letters* 49, no. 25 (1982): 1804–1807.

Angelopoulos, A., et al. (CPLEAR Collaboration). "First Direct Observation of Time-Reversal Non-Invariance in the Neutral-Kaon System." *Physics Letters B* 444 (1998): 43–51.

Aspect, Alain, Philippe Grangier, and Gérard Roger. "Experimental Realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A New Violation of Bell's Inequalities." *Physical Review Letters* 49, no. 2 (1982): 91–94.

ATLAS Collaboration. "Evidence for Light-by-Light Scattering in Heavy-Ion Collisions with the ATLAS Detector at the LHC." *Nature Physics* 13 (2017): 852–858.

ATLAS Collaboration. “Observation of Light-by-Light Scattering in Ultraperipheral Pb+Pb Collisions with the ATLAS Detector.” *Physical Review Letters* 123 (2019): 052001.

Beggs, John M., and Dietmar Plenz. “Neuronal Avalanches in Neocortical Circuits.” *Journal of Neuroscience* 23, no. 35 (2003): 11167–11177.

Bekenstein, Jacob D. “Universal Upper Bound on the Entropy-to-Energy Ratio for Bounded Systems.” *Physical Review D* 23 (1981): 287–298.

Bell, John S. *Speakable and Unspeakable in Quantum Mechanics.* 2nd ed. Cambridge: Cambridge University Press, 2004. The paper “Free Variables and Local Causality.”

Bell, John S. “On the Einstein Podolsky Rosen Paradox.” *Physics* 1, no. 3 (1964): 195–200.

Bennett, Charles H. “Logical Reversibility of Computation.” *IBM Journal of Research and Development* 17, no. 6 (1973): 525–532.

Bohm, David. “A Suggested Interpretation of the Quantum Theory in Terms of ‘Hidden’ Variables, I and II.” *Physical Review* 85 (1952): 166–193.

Bohr, Niels. “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?” *Physical Review* 48 (1935): 696–702.

Bohr, Niels. “The Quantum Postulate and the Recent Development of Atomic Theory.” *Nature* 121 (1928): 580–590.

Bostrom, Nick. “Are You Living in a Computer Simulation?” *Philosophical Quarterly* 53, no. 211 (2003): 243–255.

Brewer, Eric A. “Towards Robust Distributed Systems.” Keynote address, ACM Symposium on Principles of Distributed Computing, Portland, Oregon, 2000.

Butterfield, Jeremy, and Chris J. Isham. “On the Emergence of Time in Quantum Gravity.” arXiv: gr-qc/9901024, 1999.

Callender, Craig. “Is Time ‘Handed’ in a Quantum World?” *Proceedings of the Aristotelian Society* 100 (2000): 247–269.

Callender, Craig. “Thermodynamic Asymmetry in Time.” In *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Fall 2021.

Cantor, Georg. “Über eine Eigenschaft des Inbegriffes aller reellen algebraischen Zahlen.” *Journal für die reine und angewandte Mathematik* 77 (1874): 258–262.

Cantor, Georg. "Über eine elementare Frage der Mannigfaltigkeitslehre." *Jahresbericht der Deutschen Mathematiker-Vereinigung* 1 (1891): 75–78.

Carter, Nathan. *Visual Group Theory.* Washington, DC: Mathematical Association of America, 2009.

Chamseddine, Ali H., and Alain Connes. "The Spectral Action Principle." *Communications in Mathematical Physics* 186 (1997): 731–750.

Christenson, J. H., J. W. Cronin, V. L. Fitch, and R. Turlay. "Evidence for the 2π Decay of the K_2^0 Meson." *Physical Review Letters* 13, no. 4 (1964): 138–140.

Conway, John H., and Simon Kochen. "The Strong Free Will Theorem." *Notices of the American Mathematical Society* 56, no. 2 (2009): 226–232.

Conway, John, and Simon Kochen. "The Free Will Theorem." *Foundations of Physics* 36, no. 10 (2006): 1441–1473.

Davis, Tamara M., and Charles H. Lineweaver. "Expanding Confusion: Common Misconceptions of Cosmological Horizons and the Superluminal Expansion of the Universe." *Publications of the Astronomical Society of Australia* 21, no. 1 (2004): 97–109.

Earman, John. *A Primer on Determinism.* Dordrecht: D. Reidel, 1986.

Earman, John. "What Time Reversal Invariance Is and Why It Matters." *International Studies in the Philosophy of Science* 16, no. 3 (2002): 245–264.

Einstein, Albert, Boris Podolsky, and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47, no. 10 (1935): 777–780.

Einstein, Albert. "Die Grundlage der allgemeinen Relativitätstheorie." *Annalen der Physik* 49 (1916): 769–822.

Einstein, Albert. "Zur Elektrodynamik bewegter Körper." *Annalen der Physik* 17 (1905): 891–921.

Einstein, Albert. "Über das Relativitätsprinzip und die aus demselben gezogenen Folgerungen." *Jahrbuch der Radioaktivität und Elektronik* 4 (1907): 411–462.

Einstein, Albert. "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt." *Annalen der Physik* 17 (1905): 132–148.

Fan, X., T. G. Myers, B. A. D. Sukra, and G. Gabrielse. "Measurement of the Electron Magnetic Moment." *Physical Review Letters* 130 (2023): 071801.

Feynman, Richard P., Robert B. Leighton, and Matthew Sands. *The Feynman Lectures on Physics*, vol. 3. Reading, Massachusetts: Addison-Wesley, 1965. Chapter 1, Quantum Behavior.

Ghirardi, G. C., A. Rimini, and T. Weber. "A General Argument against Superluminal Transmission through the Quantum Mechanical Measurement Process." *Lettere al Nuovo Cimento* 27, no. 10 (1980): 293–298.

Gilbert, Seth, and Nancy Lynch. "Brewer's Conjecture and the Feasibility of Consistent, Available, Partition-Tolerant Web Services." *ACM SIGACT News* 33, no. 2 (2002): 51–59.

Giustina, Marissa, et al. "Significant-Loophole-Free Test of Bell's Theorem with Entangled Photons." *Physical Review Letters* 115 (2015): 250401.

Gödel, Kurt. "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I." *Monatshefte für Mathematik und Physik* 38 (1931): 173–198.

Hameroff, Stuart, and Roger Penrose. "Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness." *Mathematics and Computers in Simulation* 40 (1996): 453–480.

Handsteiner, Johannes, et al. "Cosmic Bell Test: Measurement Settings from Milky Way Stars." *Physical Review Letters* 118 (2017): 060401.

Hawking, S. W., and G. F. R. Ellis. *The Large Scale Structure of Space-Time.* Cambridge: Cambridge University Press, 1973.

Hawking, Stephen W. "Particle Creation by Black Holes." *Communications in Mathematical Physics* 43 (1975): 199–220.

Hawking, Stephen, and Leonard Mlodinow. *The Grand Design.* New York: Bantam, 2010.

Heisenberg, Werner. "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik." *Zeitschrift für Physik* 43 (1927): 172–198.

Hensen, B., et al. "Loophole-free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres." *Nature* 526 (2015): 682–686.

Hoefer, Carl. "Causal Determinism." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta. Spring 2016 edition.

Hoffman, Donald D. *The Case Against Reality: Why Evolution Hid the Truth from Our Eyes.* New York: W. W. Norton, 2019.

Hossenfelder, Sabine, and Tim Palmer. "Rethinking Superdeterminism." *Frontiers in Physics* 8 (2020): 139.

Hossenfelder, Sabine. "Superdeterminism: A Guide for the Perplexed." Preprint, 2020.

Isham, Chris J. "Structural Issues in Quantum Gravity." arXiv: gr-qc/9510063, 1995.

Jacobson, Ted. "Thermodynamics of Spacetime: The Einstein Equation of State." *Physical Review Letters* 75 (1995): 1260–1263.

Janet, Paul. "Une illusion d'optique interne." *Revue philosophique de la France et de l'étranger* 3 (1877): 497–502.

Kennard, Earle H. "Zur Quantenmechanik einfacher Bewegungstypen." *Zeitschrift für Physik* 44 (1927): 326–352.

Krauss, Lawrence M. *A Universe from Nothing: Why There Is Something Rather than Nothing*. New York: Free Press, 2012.

Landauer, Rolf. "Irreversibility and Heat Generation in the Computing Process." *IBM Journal of Research and Development* 5, no. 3 (1961): 183–191.

Lees, J. P., et al. (BaBar Collaboration). "Observation of Time-Reversal Violation in the B^0 Meson System." *Physical Review Letters* 109 (2012): 211801.

Leibniz, Gottfried Wilhelm. "Principles of Nature and Grace, Based on Reason" (1714). In *Philosophical Essays*, translated by Roger Ariew and Daniel Garber. Indianapolis: Hackett, 1989.

Lorenz, Edward N. "Deterministic Nonperiodic Flow." *Journal of the Atmospheric Sciences* 20, no. 2 (1963): 130–141.

Loschmidt, Josef. "Über den Zustand des Wärmegleichgewichtes eines Systems von Körpern mit Rücksicht auf die Schwerkraft." *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Wien, Mathematisch-Naturwissenschaftliche Classe* 73 (1876): 128–142.

Mach, Ernst. *Die Mechanik in ihrer Entwickelung, historisch-kritisch dargestellt.* Leipzig: Brockhaus, 1883.

Mach, Ernst. *The Science of Mechanics: A Critical and Historical Account of Its Development.* Translated by Thomas J. McCormack. Chicago: Open Court, 1893.

Malament, David B. "The Class of Continuous Timelike Curves Determines the Topology of Spacetime." *Journal of Mathematical Physics* 18, no. 7 (1977): 1399–1404.

Maudlin, Tim. *The Metaphysics Within Physics.* Oxford: Oxford University Press, 2007.

Minkowski, Hermann. “Raum und Zeit.” *Physikalische Zeitschrift* 10 (1909): 104–111.

Nagel, Thomas. “What Is It Like to Be a Bat?” *The Philosophical Review* 83, no. 4 (1974): 435–450.

Newton, Isaac. *Philosophiae Naturalis Principia Mathematica.* London, 1687. The scholium to the definitions, on absolute and relative motion.

Noether, Emmy. “Invariante Variationsprobleme.” *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse* (1918): 235–257.

Norton, John D. “The Dome: An Unexpectedly Simple Failure of Determinism.” *Philosophy of Science* 75, no. 5 (2008): 786–798.

Penrose, Roger. *The Road to Reality: A Complete Guide to the Laws of the Universe.* London: Jonathan Cape, 2004. Chapters 30 to 34, on the interface of the two theories.

Perlmutter, Saul, et al. “Measurements of Ω and Λ from 42 High-Redshift Supernovae.” *The Astrophysical Journal* 517, no. 2 (1999): 565–586.

Planck Collaboration. “Planck 2018 Results. VI. Cosmological Parameters.” *Astronomy and Astrophysics* 641 (2020): A6.

Popper, Karl R. *The Logic of Scientific Discovery.* London: Hutchinson, 1959.

Price, Huw. *Time's Arrow and Archimedes' Point.* Oxford: Oxford University Press, 1996.

Rauch, Dominik, et al. “Cosmic Bell Test Using Random Measurement Settings from High-Redshift Quasars.” *Physical Review Letters* 121 (2018): 080403.

Raychaudhuri, Amal Kumar. “Relativistic Cosmology. I.” *Physical Review* 98, no. 4 (1955): 1123–1126.

Riess, Adam G., et al. “Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant.” *The Astronomical Journal* 116, no. 3 (1998): 1009–1038.

Rovelli, Carlo. *Quantum Gravity.* Cambridge: Cambridge University Press, 2004.

Schrödinger, Erwin. “Die gegenwärtige Situation in der Quantenmechanik.” *Naturwissenschaften* 23 (1935): 807–812, 823–828, 844–849.

Schrödinger, Erwin. “Quantisierung als Eigenwertproblem.” *Annalen der Physik* 79 (1926): 361–376.

Shalm, Lynden K., et al. “Strong Loophole-Free Test of Local Realism.” *Physical Review Letters* 115 (2015): 250402.

Smolin, Lee. *Three Roads to Quantum Gravity.* London: Weidenfeld & Nicolson, 2001.

Tegmark, Max. “Importance of Quantum Decoherence in Brain Processes.” *Physical Review E* 61 (2000): 4194–4206.

The BIG Bell Test Collaboration. “Challenging Local Realism with Human Choices.” *Nature* 557 (2018): 212–216.

Turing, Alan M. “On Computable Numbers, with an Application to the Entscheidungsproblem.” *Proceedings of the London Mathematical Society* s2-42, no. 1 (1936): 230–265.

Verlinde, Erik. “On the Origin of Gravity and the Laws of Newton.” *Journal of High Energy Physics* 2011, no. 4 (2011): 29.

Wheeler, John Archibald. “Information, Physics, Quantum: The Search for Links.” In *Proceedings of the 3rd International Symposium on Foundations of Quantum Mechanics*, Tokyo, 1989.

Wolfram, Stephen. *A Project to Find the Fundamental Theory of Physics.* Wolfram Media, 2020.

Zeh, H. Dieter. *The Physical Basis of the Direction of Time.* 5th ed. Berlin: Springer, 2007.

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