VOL 2

The Ontological Limits of Physical Explanation Measurement, Collapse and Boundary Phenomena in Quantum Physics

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OPERATORIC RESEARCH CORPUS - STUDIES IN WORLD-FORMATION

Operatoric Research Corpus
Studies in World-Formation

Section I

Ontology and Physics

Volume 2

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Measurement, Collapse and Boundary Phenomena in Quantum Physics

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2026

DOI: 10.5281/zenodo.18983359

Impressum / Publication Information

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Zenodo Community: Operatoric Research Corpus Archive

First published: 2026

This publication is deposited in the German National Library (Deutsche Nationalbibliothek) as a network publication.

DOI: https://doi.org/10.5281/zenodo.18983359

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Abstract

This volume brings together a series of contributions on the ontology of fundamental problems in physics, in particular the measurement problem of quantum mechanics, the collapse of the wave function, the relationship between quantum mechanics and relativity theory, as well as boundary phenomena such as black holes, renormalization, and vacuum energy.

The point of departure of these investigations is the thesis that numerous paradoxes of modern physics do not primarily result from insufficient physical theories, but from a categorical misaddressing. Transitions that concern the very conditions of world stability—especially the transition from possibility to facticity—are often interpreted as dynamical processes within an already stabilized world. This gives rise to explanatory programs that attempt to bridge this boundary by means of additional mechanisms, ontologies, or informational structures.

The texts collected in this volume pursue an alternative strategy. They understand the so-called collapse of the wave function not as a physical process, but as an irreversible constriction of a space of possibility through which objectivity and the direction of time first emerge at all. The concept of indimergence designates the boundary act in which possibility passes into facticity without itself being describable as an event within the world.

On the basis of this determination, central approaches in the foundations of quantum mechanics—particularly dynamical collapse models, Many-Worlds interpretations, and information-theoretic ontologies—are comparatively analyzed. It becomes evident that, despite their differences, they share a common presupposition: the assumption that the transition from possibility to facticity must itself be explicable within physical description.

The contributions in this volume instead propose to read the measurement problem and related paradoxes as indications of structural limits of physical description. From this perspective, other fundamental problems—such as the tension between quantum mechanics and relativity theory, the information paradoxes of black holes, or divergences in field theory—no longer appear primarily as unsolved technical puzzles, but as boundary phenomena of world formation itself.

The volume therefore does not present itself as an alternative physical theory, but as an ontological clarification of the conditions under which physical theories are able to describe a world at all.

Keywords: quantum measurement problem, wave function collapse, Many-Worlds interpretation, foundations of quantum mechanics, quantum measurement, philosophy of physics, ontology of physics, black hole information paradox, renormalization, cosmological constant problem, vacuum energy, indimergence, possibility and facticity, limits of physical explanation

Contents

Introduction

Modern physics faces a number of problems that, despite the enormous empirical success of the theory, have remained unresolved to this day. Among these are the measurement problem of quantum mechanics, the status of wave function collapse, the tension between quantum mechanics and relativity theory, the information paradox of black holes, and persistent divergences in quantum field theory. These difficulties are usually interpreted as signs of incomplete theories or missing dynamical mechanisms. Accordingly, many research programs attempt to introduce additional processes, hidden variables, new ontologies, or more comprehensive mathematical frameworks in order to extend existing theories or to unify them.

The contributions assembled in this volume begin from a different observation. Many of these apparently unrelated problems share a common structural feature. In each case, physics encounters a transition that does not merely occur within an already stabilized world but concerns the conditions under which such a world can appear at all.

This becomes particularly visible in the measurement problem of quantum mechanics. The transition from a multiplicity of possible states to a uniquely determined observation is typically treated as a physical process unfolding in time and therefore, in principle, susceptible to further dynamical analysis. The texts collected here question precisely this assumption.

The central claim is that the so-called collapse of the wave function cannot be understood as a dynamical event within the world. Rather, it marks a boundary act in which a space of possibilities becomes irreversibly restricted to a factual world configuration. Objectivity, in this view, does not arise through the revelation of an already determined state but through the exclusion of alternative possibilities. The transition from possibility to facticity is therefore not a physical process but a structural condition for the emergence of a stable world.

To articulate this boundary character more precisely, several contributions introduce the concept of indimergence. Indimergence designates the point at which possibility passes into facticity without itself being describable as a temporal process. It marks a limit of physical description: wherever indimergence becomes operative, concepts such as state, dynamics, or information lose their direct applicability because they already presuppose a stabilized world structure.

From this perspective, several classical approaches to the foundations of quantum mechanics receive a new interpretation. Dynamical collapse models attempt to model the transition to facticity as a physical process and therefore extend the dynamics of quantum mechanics. Many-Worlds interpretations avoid the problem by ontologically realizing all possible outcomes. Information-theoretic approaches, in turn, interpret the transition primarily as an update of knowledge. Despite their differences, these approaches share a common assumption: they treat the transition from possibility to facticity as something that must be explainable within the world.

The following texts argue that this expectation is itself part of the difficulty. If the transition to facticity constitutes the condition under which a world can appear as a stable order of objects, states, and processes, then this transition cannot itself be described in the same conceptual terms. Instead, it marks a boundary at which the ontological presuppositions of physical explanation become visible.

Seen from this boundary perspective, several seemingly independent problems of modern physics can be placed within a common framework. The tension between quantum mechanics and relativity theory, for example, can be read as the expression of two different modes of describing the same structural situation: an open structure of possibility on the one hand and a stabilized world order on the other. In a similar way, the information paradox of black holes, divergences in field theory, and the cosmological constant problem can be interpreted as phenomena that arise at the limits of world accessibility and stabilization.

The volume therefore does not aim to develop an alternative physical theory or to replace existing models. Its aim is rather to clarify the ontological conditions under which physical explanation becomes possible at all. The texts collected here are therefore best understood as boundary analyses: investigations of situations in which the concepts of object, information, dynamics, and world encounter their own presuppositions.

At precisely these points it becomes visible that some of the most persistent paradoxes of modern physics may not result from missing mechanisms but from structural limits of description. Instead of attempting to bridge these limits through increasingly complex theoretical constructions, it may be more productive to recognize them as such.

The following chapters examine several such boundary phenomena in contemporary physics, including quantum measurement, collapse interpretations, information-theoretic ontologies, black hole physics, renormalization, and the cosmological constant problem.

Wave Function Collapse Is Not a Dynamical Process
On the Irreversible Constriction of Possibility, Time, and Objectivity

DOI: https://doi.org/10.5281/zenodo.18366599

Abstract

The so-called collapse of the wave function is still regarded as one of the central unresolved problems of quantum mechanics. This paper argues that this problem does not stem from an incomplete physical theory, but from a categorical misaddressing. The collapse is usually understood as a physical process that takes place within time and should, in principle, be further analyzable in dynamical terms. This assumption, however, is itself part of the problem.

On the basis of an ontological distinction between possibility and factuality, it is shown that the collapse is not a process, but an irreversible constriction of an ontological space of possibility. Measurement is not understood as an epistemic act, but as object-making: a coercion toward objectivity through which possibility is excluded and the world is fixed to a single factual continuation. The collapse does not mark a transition between states, but a boundary act at which the language of processes loses its validity.

In this understanding, the collapse is not an event in time, but a generator of time direction. Time appears as the trace of irreversible constrictions, not as a presupposed background

parameter. The position advanced here thereby explains why the collapse cannot, in principle, be mechanistically explained without introducing additional entities or dynamics.

The paper proposes that the measurement problem should no longer be treated as a question of a hidden mechanism, but rather as a boundary phenomenon in which the ontological presuppositions of physical description themselves become visible. This shifts the focus from processes and mechanisms to conditions, regimes, and boundaries of world-formation.

I. Preliminary Remark: Why the Term "Collapse" Itself Is Problematic

The term *collapse of the wave function* belongs to the most remarkable self-deceptions of modern physics. It suggests a physical occurrence where, in fact, a conceptual shift takes place. "Collapse" sounds like a process, like an event in time, like a dynamics that should in principle be further analyzable. It is precisely this implication that has kept the measurement problem in a loop for more than a hundred years.

What, then, actually collapses here?

Not a particle, not a field, not an energy distribution. What disappears is the openness of possibility. The term "collapse" conceals this fact by translating it into a language of mechanics that no longer holds at this point.

The first step toward a clearer understanding of the so-called collapse therefore does not consist in a new theory, but in a deconstruction of the term itself.

II. Possibility Is Not an Incomplete State

The wave function does not describe a hidden state of the world that is merely inaccessible to our knowledge. Nor does it describe a multiplicity of actually existing objects. It describes a space of possibility whose ontological status is fundamentally different from that of an actualized state.

Physical language tends to treat possibility as deficient reality: as something that is not yet fully determined. This view is deeply classically shaped. It projects object logic onto a domain that is characterized precisely by not being an object.

Possibility is not a weak state, but a different topological mode of world-binding.

As long as the possibility of world-formation based on gaps rather than on things is not taken seriously, the transition from possibility to factuality necessarily appears puzzling—because it is meant to be described with concepts that are made only for states.

III. Measurement as Object-Making

What is called measurement in quantum mechanics is not a neutral act of cognition. Ontologically considered, measurement is a coercion toward objectivity. It enforces a constriction of the space of possibility to exactly one factual world configuration.

Before the measurement, there is no position of the electron.
After the measurement, there is one.

This difference is not epistemic, but ontological. Measurement does not reveal a pre-existing position; it produces objectivity by excluding possibility—the open gap of what could be. Objectivity is thus not a ground state of the world, but the result of a transition that is itself not objectifiable.

This transition is based on an irreversible constriction of possibility. With it, the originary character of the space of possibility is lost. What remains is a solidified space–time relation in which the world appears only as an object relation. The space of possibility is not merely reduced, but structurally simplified: it contracts, hardens, and loses connectivity.

Objectivity thus does not arise as clarification, but as a form of loss. With every act of object-making, possibility is consumed, and with it disappears the openness that could sustain the world beyond the object. In this sense, objectivity is always finite: it makes the world available, but at the same time mortal.

The so-called collapse is therefore not a physical process within the world, but the boundary act through which the world as an objective structure comes into being at all.

IV. The Collapse Is Not a Dynamics, but a Constriction

If one frees the concept of collapse from its mechanistic metaphoricity, a sober structure remains: constriction. The collapse does not designate a process, but an irreversible transformation of the space of possibility itself.

What occurs is neither a movement nor a breakdown. The space of possibility is constricted. From a multiplicity of connectable futures, exactly one factual continuation emerges. Nothing "collapses," nothing is transported, nothing takes place in the classical sense. What changes is exclusively the space of what is still possible.

This constriction cannot be further decomposed, because it is not a state. It possesses no duration, no intermediate stages, and no internal dynamics. It is not a process that could be described, analyzed, or simulated. Any attempt to nevertheless mechanize it inevitably leads to object inflation: additional fields, additional dynamics, additional worlds that do not solve the actual problem but conceal it.

The collapse is therefore not misunderstood, but misaddressed. It is sought where it cannot in principle be found: in the domain of processes. In fact, it marks a boundary at which the language of processes itself loses its validity.

V. Collapse as Local Time Curvature

The constriction of the space of possibility has an immediate temporal consequence. Before the collapse, multiple connectable futures exist. After the collapse, exactly one exists. The collapse is therefore not an event in time, but a generator of time direction.

Time does not appear here as a presupposed background parameter, but as the trace of irreversible constrictions. Each collapse marks a point at which possibility is irretrievably consumed. In this sense, the collapse is a local point of curvature of time.

What is irreversibly lost here is neither energy nor information. Energy can be transformed, information can in principle be reconstructed. Lost possibility cannot. This irreversibility is more fundamental than thermodynamic entropy, because it is not statistical, but ontological.

In this understanding, time is not the measure of change, but the history of what is no longer possible.

That this structure cannot be empirically isolated is not a weakness, but a consequence of its boundary position.

VI. Seinsverschiebung (Shift of Being) Instead of Explanation

What takes place here is not an incomplete physical description, but a Seinsverschiebung (shift of being): the transition from possibility to factuality. Physics can mark this transition, but it cannot describe it without overstepping its own concepts.

By *Seinsverschiebung (shift of being)* I designate the consequence that every naming of an object, every measurement, every fixation necessarily leads to the disappearance of the potential of that which thereby becomes an object. It becomes absent. This absence is not a mere lack, but an effective void. Within it, a topological shift occurs in which the space of possibility condenses in relation to what is absent.

The topology of the world changes its form because what is absent can no longer be carried by a world in which possibility itself no longer exists. A sphere emerges, a temporally closed space, a bound substitute structure of the space of possibility, whose order is determined not by openness, but by absence. This does not posit an additional domain or layer of the world, but the binding form of the remaining relations produced by constriction. This structure is neither a reconstructive simulation nor an inner image of possibility, but a topological residual form: an order shaped by loss, which does not represent possibility, but replaces it.

Within this substitute structure, things become conditions. This conditionality feeds back onto all further bindings, shifts relations, stabilizes objectivity, and fixes the world as a finite structure that is only continuable, no longer open.

Seinsverschiebung (shift of being) thus acts like a filter in front of the space of possibility: a compelling topology that follows constriction and correspondingly shifts and distorts all relations. What becomes visible are "frozen" things—static architectures in which tension forces are at work that arise from this distortion.

This act, however, is not a process in the sense of a thing. Seinsverschiebung (shift of being) is not a causal consequence, but an implication: it is effective without being describable as a process or a cause. It is not a dynamics, not magnetism, not an equalization of energy. It is operatorics: the fundamental condition from which physical processes can arise at all. Everything and nothing cannot be at the same time. The mortal, finite thing is the consequence of this paradox.

What is described here is not a deficit of physics. It is a structural boundary. The error begins where this boundary is not acknowledged and where, instead, ever finer explanations are sought. The collapse then becomes a riddle, because one demands of it that it be a thing.

It is not.

VII. Consequence: A New Address of the Measurement Problem

The measurement problem is not resolved by a better theory of collapse, but by a correct ontological address. The collapse is not an open research problem in the sense of a missing equation or an undiscovered dynamics. It is a boundary phenomenon at which it becomes visible that reality is not fully actualizable.

The productive shift therefore does not consist in continuing to ask how the collapse occurs, but in examining how systems deal with this boundary. What is decisive is not the collapse itself, but the manner in which possibility is still kept open, recurrently taken up again, or finally consumed before its definitive constriction.

This shifts the focus of analysis: away from mechanisms and causal models, toward regimes; away from objects, toward boundaries; away from processes, toward the question of world-capability. The measurement problem is thus not solved, but resituated—at the point where physics, ontology, and time interlock.

The position advanced here is neither an empirical hypothesis nor a mere language analysis, but an ontological diagnosis of the conditions of physical description.

VII.a What This Work Does Not Claim

This work makes no claim to formulate a new theory of collapse in the physical sense. It introduces neither a new mechanism nor does it supplement quantum theory with additional dynamics, fields, or entities. In particular, it does not claim to render the collapse calculable, simulable, or causally explainable.

Likewise, this work provides neither an alternative interpretation of individual measurement outcomes nor a revision of the formal structure of quantum mechanics. The perspective developed here does not compete with existing mathematical models, but addresses a different level: the ontological address of the concept of collapse itself.

Nor is collapse identified here with consciousness or derived from mental states. Consciousness is, for the present argument, neither the cause nor the explanation of collapse, but at most a possible special case of recurrent engagement with the boundary described.

The central thesis of this work is therefore explicitly negative: it consists in showing why collapse cannot be an object of mechanistic explanation, without this being misunderstood as a deficit of physics.

VII.b Consequences for the Physical Question

If collapse is understood not as a physical process, but as an irreversible constriction of a space of possibility, the focus of physical analysis necessarily shifts. In place of the search for hidden dynamics comes the investigation of boundary regimes, transitions, and conditions under which possibility is transferred into factuality.

What then becomes physically relevant is no longer the collapse itself, but the structure of the situations in which constriction occurs: the stability or instability of openness, the role of recurrence, the distinction between singular object-making and repeated re-binding to possibility. Instead of isolated end states, worldlines, continuation spaces, and regimes of irreversible fixation come into view.

This shift does not replace existing physics. It does, however, alter the question under which physical models are read and further developed. The collapse no longer appears as an unresolved detail problem, but as a marker of a boundary at which it is decided which forms of world-capability can be physically realized.

The validity of the Born rule remains unaffected by this analysis, since it does not describe a dynamics of collapse, but the structure of possibility prior to its constriction.

VIII. Concluding Statement

The collapse of the wave function is not a physical process, but the irreversible constriction of an ontological space of possibility. Time is the trace of these constrictions. Whoever seeks to explain the collapse misses it; whoever understands it as a boundary recognizes why it cannot be explainable.

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Why the Measurement Problem Is Not Dynamically Solvable
A Boundary Determination with Respect to Collapse Models, Many-Worlds, and Information-Based Ontologies

DOI: https://doi.org/10.5281/zenodo.18379725

Abstract

The measurement problem of quantum mechanics is predominantly treated in contemporary foundations research as an unresolved problem of dynamics or ontology. Accordingly, dominant solution approaches aim either at additional collapse mechanisms (e.g., GRW-type models), at ontological branching (Many-Worlds interpretations), or at an information-theoretic reinterpretation of state and measurement.

The present contribution advances a different thesis. It shows that, despite their methodological differences, these approaches share a common categorical presupposition: they treat the transition from possibility to facticity as an intra-worldly describable occurrence—whether as a dynamical process, an ontological splitting, or a state update. It is precisely this presupposition that is called into question here.

Starting from an ontological distinction between possibility and facticity, it is argued that measurement cannot be understood as a temporal event within an already structured world. Rather, it marks a boundary at which temporal, processual, and informational descriptions lose their applicability. The transition to objectivity is therefore not an explainable event, but an irreversible restriction of the space of possibility, through which world becomes factically binding in the first place.

Against this background, dynamical collapse models, Many-Worlds interpretations, and information-theoretic ontologies are comparatively analyzed. The aim is not a refutation of these approaches, but a precise boundary determination: it is shown in what way they each provide formally successful answers to partial aspects of the measurement problem, while at the same time presupposing the categorical status of facticization that they claim to explain.

The contribution does not understand itself as an alternative interpretation of quantum mechanics, but as an ontological clarification of its domain of validity. It proposes that the measurement problem should no longer be treated as the search for a hidden mechanism, but as an indication of a structural boundary of physical description itself.

1. The Measurement Problem as a Problem of Interpretation

The measurement problem of quantum mechanics is traditionally described as a tension between formal superposition and unambiguous observation. While the temporal evolution of the quantum-mechanical state proceeds continuously and deterministically according to the Schrödinger equation, measurement outcomes occur discretely, unambiguously, and factically. This discrepancy forms the point of departure for a wide range of interpretative approaches.

In contemporary foundations research, the measurement problem is often understood as a deficit of dynamical description. Accordingly, many solution strategies aim either to introduce additional physical processes, to ontologically extend the formal state space, or to redefine the meaning of measurement in informational or observer-dependent terms. Despite significant differences, these approaches share the assumption that the transition from quantum-mechanical possibility to classical facticity must in principle be explicable.

This expectation of a mediating explanation is itself rarely subjected to systematic analysis. The question of whether the transition to facticity can be described at all as an intra-worldly occurrence—or whether a categorical boundary of physical description is reached here—usually remains implicit. The present contribution takes up this point directly.

It proposes to read the measurement problem not primarily as an unresolved mechanics, but as an indication of a structural boundary of physical description. The aim is to make this boundary explicit and to comparatively examine its consequences for prevailing solution strategies.

2. Possibility, Facticity, and the Implied Boundary of Measurement

The preceding discussion presupposes a distinction that usually remains implicit in foundational research in physics: the distinction between possibility and facticity. In the dominant solution approaches to the measurement problem, this distinction is either dynamized, ontologized, or epistemicized. What they have in common is that the transition from possibility to facticity is treated as something that can be located within the world—and thus within a continued description.

By contrast, the present contribution advances the thesis that this transition marks a categorical boundary. Possibility is not an incompletely determined state that could be supplemented by further dynamics, branching, or information processing. Rather, it designates an ontological space of openness that is irreversibly restricted by facticization itself. What occurs in measurement is therefore not the selection of an already determined state, but the loss of alternative world continuations.

In order to fix this boundary terminologically, the term indimergence is introduced in what follows. Indimergence does not designate a process, a temporal sequence, or a mediating mechanism. The term exclusively marks the boundary act in which possibility passes into facticity, without itself being describable as an intra-worldly event. Indimergence has no duration, no dynamics, and no internal structure; it is the point at which the language of states, processes, and information loses its validity.

This terminological fixation is not to be understood as the introduction of a new theory, but as a specification of what is frequently tacitly presupposed in treatments of the measurement problem. Where this boundary status is not acknowledged, pressure arises to ontologically fill possibility or to temporally extend it. It is precisely here that the familiar solution strategies take hold.

Branching ontologies such as the Many-Worlds interpretation project the totality of possible outcomes into an ontological multiplicity of factual worlds. Possibility is thereby no longer understood as the non-factual, but as an ensemble of realized alternatives. The transition to facticity is dissolved by being ontologically multiplied. What disappears in this move is not the measurement problem, but the status of possibility itself that first constitutes this problem.

Dynamical collapse models pursue a different strategy. They attempt to internalize the boundary act of facticization temporally by modeling it as a physical process. Here, too, the boundary is not acknowledged, but simulated. The collapse appears as a process within time, although this very temporal reference is itself the result of the facticization that is to be explained.

Information-theoretic ontologies, finally, treat measurement primarily as a state update or a knowledge update. Possibility is epistemically recoded and thereby decoupled from its ontological character of loss. Facticity does not appear here as an irreversible binding of world, but as a formal revision of a descriptive state.

What these approaches share is that they fill the space of possibility with being—whether in the form of additional worlds, additional dynamics, or additional informational structures. In doing so, however, precisely that boundary is obscured at which possibility disappears as possibility. Indimergence names this boundary without crossing it. It does not explain the transition, but marks why it cannot be explained in the sense of an intra-worldly dynamics.

3. Dynamical Collapse Models and the Simulation of the Boundary

Dynamical collapse models such as GRW or CSL were developed in order to physically explicate the transition from quantum-mechanical superposition to classical facticity. They supplement the unitary dynamics of the Schrödinger equation with additional stochastic or nonlinear terms through which superpositions become unstable and macroscopically unambiguous states emerge. In this respect, they address a real deficit of purely formal interpretations: the lack of an explanation of why certain states occur factically while others do not.

From an ontological perspective, however, a decisive question remains open. Dynamical collapse models describe when and how a state reduction occurs, but not what happens categorially in the transition from possibility to facticity. Collapse is modeled as a physical process within time. In doing so, however, what is to be explained is already presupposed: a temporally structured world in which processes take place and states can succeed one another.

In the perspective advanced here, measurement does not mark a phase within a continuous course of events, but a boundary act through which temporal structure becomes effective in the first place. The attempt to describe this boundary act dynamically therefore necessarily leads to a simulation of the boundary: the transition is temporally extended in order to keep it explainable, but in doing so it loses its categorical status.

This temporal extension does not constitute an expansion of ontological reach, but a refinement within the same unit of description. The increasing degree of detail of dynamical terms creates the impression of greater explanatory depth without leaving the categorical framework within which facticization cannot be represented at all. The transition thus appears ever more differentiated, but not in principle more accessible.

Dynamical collapse models are not wrong in this sense. They are formally consistent, empirically connectable, and solve specific problems of macroscopicity. Their ontological reach is nevertheless limited. By treating collapse as an intra-worldly process, they shift the question of facticization into a level of description that already presupposes this facticization. The loss of possibility then appears as one physical effect among others, rather than as the condition of world-binding itself.

From the perspective of indimergence, it becomes clear why this approach runs up against a boundary. Indimergence does not designate a temporal event that could be slowed down, noised, or statistically modeled. It designates the point at which possibility is irreversibly excluded and at which the language of processes, probabilities, and dynamics loses its jurisdiction. If this point is nevertheless dynamized, an explainable mechanics emerges—however, at the cost of flattening the categorical difference between possibility and facticity.

This makes it clear that dynamical collapse models answer a different question than the one under consideration here. They explain the stabilization of states within an already factual world. They do not explain why, and under what conditions, world becomes factual at all.

4. Many-Worlds Ontologies and the Expansion of the Space of Possibility

Many-Worlds interpretations were developed in order to resolve the measurement problem without introducing additional dynamics or collapse mechanisms. They adhere to the unitary temporal evolution of the Schrödinger equation and avoid state reduction by treating all possible measurement outcomes as equally real. What appears as collapse is interpreted in this perspective as a branching of the world. Facticity is not produced, but distributed.

In this respect, Many-Worlds ontologies constitute a consistent and formally elegant approach. They eliminate the rupture between quantum-mechanical dynamics and classical description by resorting to an expansion of ontology. The price of this consistency, however, is high: the transition from possibility to facticity is not explained, but annulled. Possibility no longer appears as the non-factual, but as an ensemble of factically realized alternatives.

From an ontological perspective, this entails a displacement of the problem. The act of measurement is no longer treated as a boundary phenomenon, but as a mere difference of perspective within an ontologically complete totality. The question of why this world binds rather than another is replaced by the assumption that all worlds exist equally. Facticization is thereby not understood, but neutralized.

In the perspective advanced here, this strategy constitutes a form of expansion. The space of possibility is ontologically filled in order to avoid the loss of possibility. Precisely thereby, however, the status of possibility is lost that first constitutes the measurement problem. Possibility becomes being; openness is replaced by multiplicity. The boundary at which possibility is irreversibly excluded disappears from the space of description.

This expansion creates the impression of greater ontological reach. In fact, however, it does not provide access to the boundary act of facticization, but circumvents it. Where everything is realized, nothing can become factual. The transition to objectivity is not explained, but rendered superfluous.

From the perspective of indimergence, it becomes clear why this approach runs up against a categorical boundary. Indimergence designates precisely the irreversible exclusion of alternative world continuations. If this exclusion is ontologically denied, formal dynamics may remain fully intact, yet the concept of world loses its binding significance. World then appears as an additive totality rather than as a historically and irreversibly conditioned existence.

It thus becomes evident that Many-Worlds ontologies do not solve the measurement problem, but transform it. They explain the formal consistency of quantum-mechanical dynamics under maximal ontology. They do not explain why world becomes factual at all—and it is precisely this question that is systematically suspended by the expansion of the possible.

5. Information-Theoretic Ontologies and the Epistemicization of the Boundary

Information-theoretic approaches to the measurement problem dispense with both additional collapse dynamics and ontological branching. Instead, they interpret the quantum-mechanical state primarily as a carrier of information, knowledge, or expectation. Measurement appears in this perspective not as a physical transition, but as an update of an informational state. The focus thus shifts from the question of the being of the world to the question of its description.

These approaches possess considerable methodological strengths. They are conceptually economical, avoid ontological inflation, and integrate well into the formal structure of quantum mechanics. In particular, they bypass classical paradoxes of the measurement problem by determining the status of the quantum-mechanical state not ontologically, but functionally or epistemically. Precisely herein, however, also lies their ontological limitation.

From the perspective advanced here, the transition from possibility to facticity in information-theoretic ontologies is not explained, but displaced. Possibility no longer appears as ontological openness, but as the indeterminacy of a state of knowledge. Facticity is accordingly not understood as an irreversible binding of world, but as a revision or update of information. The loss of possibility is thereby epistemically recoded and stripped of its ontological character.

This recoding has far-reaching consequences. Information is always bound to already stabilized states. It presupposes objectivity rather than producing it. Measurement as information gain or state update can therefore only be meaningfully described within an already factual world. The question of why world becomes factual at all remains unanswered here as well.

In information-theoretic ontologies, the boundary of facticization does not disappear through expansion or dynamization, but through epistemicization. The boundary act is transformed into an act of description. What would have to be thought as an ontological transition now appears as a perspectival shift within a descriptive framework. The categorical difference between possibility and facticity is thereby not addressed, but tacitly neutralized.

From the perspective of indimergence, it becomes clear why this approach, too, runs up against a boundary. Indimergence designates the irreversible exclusion of possibility, not the revision of a state of knowledge. Where measurement is primarily understood as information processing, there is no room for ontological loss. World appears as fully reconstructible, although its facticity rests precisely on a non-reconstructible transition.

It thus becomes evident that information-theoretic ontologies provide a precise analysis of description, knowledge, and formal consistency. They do not, however, explain under which conditions world itself becomes binding. The measurement problem is not solved, but transformed into an epistemic question—and thereby removed from the domain of ontological clarification.

6. Measurement as a Boundary Phenomenon – Non-Computability and World-Binding

The preceding sections have shown that the dominant solution strategies to the measurement problem, despite their differences, respond to a common difficulty: the transition from possibility to facticity. Dynamical collapse models, branching ontologies, and information-theoretic approaches differ in their methodology, but not in their implicit presupposition that this transition must in principle be treatable within a continued description. It is precisely this presupposition that proves to be problematic.

In the perspective advanced here, measurement is not an intra-worldly occurrence that could be explained by additional dynamics, ontological expansion, or epistemic recoding. Rather, it marks a boundary at which possibility is irreversibly excluded and through which world becomes factically binding in the first place. This boundary is not describable in temporal, processual, or informational terms. It is the condition of the possibility of description, not its object.

In this context, the repeatedly raised reference to the non-computability of collapse is of particular significance. In particular, Roger Penrose has argued that objective state reductions are in principle not algorithmically computable and therefore evade complete simulation. This finding touches a real boundary of formal description and marks an important insight within foundational research in physics.

The approach advanced here, however, shifts this finding in its categorical significance. Non-computability is not understood as a special property of a physical process, but as the signature of a boundary at which process description itself loses its jurisdiction. Collapse is not non-computable because it would be a special physical process; it is non-computable because it does not constitute a process in the intra-worldly sense.

Indimergence designates this boundary precisely. It marks the point at which possibility can no longer be transformed, distributed, or updated, but is irreversibly lost. At this point, temporal directionality, objectivity, and world-binding arise simultaneously. Any theory that attempts to model this transition as a computable, branching, or information-processing process already presupposes what is here to be grounded.

From this perspective, the measurement problem no longer appears as an unresolved detail of quantum dynamics, but as an indication of a structural boundary of physical description. It does not show that a deeper dynamics is missing, but that at this point no dynamics in the sense of intra-worldly processes can apply. Measurement is not a mechanism, but a boundary-setting.

The present contribution therefore does not understand itself as an alternative interpretation of quantum mechanics, nor as a proposal for an extended physical theory. It formulates a boundary determination: a clarification of what physical description can accomplish—and what it must necessarily presuppose in order to be able to describe world at all.

7. Conclusion: On the Scope and Limit of Physical Explanation

The present contribution has treated the measurement problem of quantum mechanics not as a deficit of an as yet incomplete dynamics, but as an indication of a structural boundary of physical description. By examining dynamical collapse models, branching ontologies, and information-theoretic approaches, it has been shown that these strategies choose different ways of keeping the transition from possibility to facticity explainable—while in each case circumventing, in a specific manner, the very boundary they address.

The boundary determination introduced here does not claim to correct or replace physical theories. It modifies no equations and disputes no empirical results. Its contribution lies instead in clarifying the ontological presuppositions under which physical description is possible at all. In this light, measurement does not appear as another event to be explained, but as the point at which explanation itself encounters its condition.

This perspective has two consequences. First, it explains why the measurement problem has not disappeared despite decades of theoretical refinement: it is not a residual technical problem, but a categorical boundary. Second, it makes intelligible why formal consistency, dynamical elegance, or informational economy alone are insufficient to capture facticization.

The contribution therefore does not argue for a new interpretation of quantum mechanics, but for a shift in the question. Instead of searching for the mechanism of measurement, it proposes to read measurement as a boundary phenomenon—as the signature of that which physical theories must necessarily presuppose without being able to produce it themselves.

The boundary determination described here is consistent with earlier works in which measurement was described as the spatial stabilization of determinacy; the present analysis clarifies the pre-ontological boundary status that compels this stabilization in the first place.

Measurement thus appears not as a mechanism still to be explained, but as the signature of a boundary at which physical explanation necessarily comes to an end.

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This work operates operatorically rather than discursively; its claims are derived from internal structural invariance rather than from literature synthesis.

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Without a Path:
Why Quantum Mechanics and Relativity Imply Each Other Without Mediation

DOI: https://doi.org/10.5281/zenodo.18375589

Abstract

The persistent incompatibility between quantum mechanics (QM) and general relativity (GR) is commonly treated in physics as a technical or mathematical problem. Either a deeper dynamics is sought that connects both theories, or a formal meta-theory that unifies their concepts.

This paper proposes a different reading. It claims neither a unification nor a correction of the existing theories. Instead, it shows that the contradiction between QM and GR is not a deficit of the theories themselves, but the consequence of an unspoken ontological omission: the lack of a determination of the transition from possibility to facticity.

At the center stands the thesis that quantum mechanics and relativity mutually imply one another without being connected by a process, a path, or a shared dynamics. The transition between openness and stability is not a physical event within the world, but a shift in the conditions under which a world can occur at all.

Using the terms *indimergence* and *shift of being (Seinsverschiebung)*, this transition is specified as a boundary structure: *indimergence* designates the non-dynamical coercion toward objectivity, while *shift of being* denotes the irreversible change of the conditions of further world-formation. From this perspective, it becomes intelligible why the conflict between QM and GR cannot be "solved" — and why precisely therein lies its ontological significance.

Section I – Conceptual Clarification and Terminological Fixation

This text begins at a point where misunderstandings arise systematically. The terms *indimergence* and *shift of being* (Seinsverschiebung) have been operatively active in the overall body of work for years, yet—particularly within physical discourse—they are frequently either metaphorized or falsely dynamized. Both practices destroy their function. For this reason, a precise and binding conceptual clarification is undertaken at the outset.

This clarification is not intended to be didactic, but disciplinary. It determines how the terms are to be read in what follows—and explicitly how they are not to be read.

1. Indimergence

Indimergence does not denote a process, a dynamics, or a temporal sequence. The term marks a boundary act at which possibility is irreversibly transferred into facticity. Indimergence is not an occurrence *in* time, but the act through which the direction of time emerges in the first place, as a trace.

Already in the text *Wave Function Collapse Is Not a Dynamical Process* (2026), it was shown that the so-called collapse of the wave function is categorically misaddressed as soon as it is interpreted as a physical event occurring within a temporal progression. There, collapse is not determined as a mechanism, but as a constriction of an ontological space of possibility. It is precisely this constriction that is here designated as indimergence.

Indimergence means:

- no transition between states,
- no transformation of something already given,
- no explicable dynamics.

Indimergence rather designates the point at which openness is excluded and objectivity is coercively produced. Measurement, in this sense, is not knowledge acquisition, but object-making. What exists after indimergence does not exist because it was already determined beforehand, but because other possibilities have been irreversibly excluded.

What is essential is this: indimergence has no duration. It is neither short nor long, neither instantaneous nor extended—it fully withdraws from temporal determination. Any temporal characterization already presupposes the result of indimergence.

2. Seinsverschiebung (Shift of Being)

The term *shift of being* (Seinsverschiebung) designates a different level. While *indimergence* marks the local coercion toward facticity, *shift of being* describes the change of the conditions under which further world-formation can occur at all.

In *The Curve of the World* (2025), *shift of being* was explicitly introduced as a pre-ontological category. It does not designate a change of state within a given space, but a shift of the conditions through which space, relation, and viability are brought forth in the first place.

Shift of being means:

- no movement in space,
- no event within a world,
- no transformation under stable conditions.

With every shift of being, an irreversible loss of possibility occurs. Not in the sense of a selection among alternatives, but in the sense of a structural constriction of what can henceforth be possible at all. World does not emerge additively, but condensationally. This condensation distorts the space of possibilities itself.

Shift of being is therefore necessarily non-reversible. A return would presuppose that the conditions under which something came into being had remained untouched. This, however, is excluded. History, in this sense, is not a sequence, but a structure of conditions.

3. Relation Between the Two Terms

Indimergence and *shift of being* are neither identical nor independent.

- *Indimergence* designates the act of facticization.
- *Shift of being* designates the consequences of this act for the conditions of further world-formation.

Indimergence produces facticity. Shift of being produces the altered world in which this facticity henceforth holds.

What is crucial is this: there is no temporal distance and no mediating process between the two. They are distinguished logically, not chronologically. Any attempt to connect them by means of a process reintroduces precisely that process logic which is explicitly criticized here.

Section I.I – Preliminary Remark on the Ontological Level

The terms *indimergence* and *shift of being* used in this text do not operate within a given ontology, but designate the conditions under which ontology becomes possible in the first place. They are therefore to be understood as pre-ontological.

Pre-ontological here does not mean "preliminary" or "indeterminate," but categorially prior: the concern is not with beings, states, or relations, but with those structural conditions of coercion through which something can appear as world, object, or relation at all.

This distinction is not terminological, but decisive. Wherever pre-ontological terms are read ontologically, precisely those category errors arise that are criticized in what follows.

Section II – Introduction: The False Expectation of Mediation

The persistent tension between quantum mechanics (QM) and general relativity (GR) is commonly understood in physics as a deficit: as an indication that a deeper theory is missing, one that could integrate or unify both approaches. This expectation is so widespread that it is itself rarely made an object of analysis. It functions as an implicit background assumption against whose horizon the conflict first appears as a problem at all.

The present text intervenes precisely at this point. It claims neither that quantum mechanics and relativity must be made compatible, nor that a new theory should take their place. Instead, it proposes to question the expectation of mediation itself. What is at issue here are not the theories, but the assumption that there must exist a mediating transition between them.

The central thesis is as follows:

Quantum mechanics and relativity imply one another without being connected by a path, a process, or a shared dynamics.

The apparent contradiction between the two theories does not arise from their incompleteness, but from the tacit assumption that there must exist a mediable transition between ontological openness and a stabilized world. This assumption is, however, categorically false. It already presupposes what is here still to be explained: a world in which processes, paths, and dynamics can be meaningfully determined.

As shown already in *Time Difference Without Neutralization* (2025), relativity theory formally describes time differences correctly, yet ontologically neutralizes these differences. Time appears there as a calculable variable within a stabilized framework, not as an irreversible condition of world-formation. Conversely, quantum mechanics exhibits a radical openness of possibilities without being able to explain how this openness can ever be coerced into stable world-relations.

The present text does not understand this asymmetry as a deficiency, but as an indication of a shared omission. What is omitted is the pre-ontological transition from possibility to facticity—that boundary act which can be described neither as a physical process nor as a dynamical path, because it marks the domain in which world, time, and processuality themselves first come into effect.

Section III – Why There Can Be No Path

The demand for a "path" between quantum mechanics and relativity theory is deeply embedded in scientific thinking. At first glance, it appears self-evident: where two descriptions of the same world are incompatible, there must be a mediating transition—a mechanism, a scale, or a dynamics that transfers one into the other.

This demand, however, is not neutral. It already presupposes precisely what is here placed in question.

A path implies:

- a shared time in which something can take place,
- a shared space or state space in which something can unfold,
- a process logic that connects initial and final states.

All of these presuppositions already belong to the side of the stabilized world. They are results of world-formation, not its conditions. A path is therefore never pre-worldly. It is always already world.

The transition at issue here, however, is not a transition *within* an existing world. It is the transition through which world comes into being at all. To demand a path between openness and stability therefore means to presuppose stability in advance. This is precisely where the category error lies.

This category error can be named with precision:

The desire for a path is itself an effect of the shift of being.

It arises only where world already exists as a structured nexus and where processes, sequences, and transformations can be meaningfully determined at all. For precisely this reason, the transition that brings about this structure cannot itself be described in processual terms without falling into logical contradiction.

Indimergence, in this sense, is not the first step of a path, but the end of the path question. It marks the point at which ontological openness is excluded and objectivity is coercively produced—without this act itself appearing as movement, transformation, or dynamics. Any such description would already presuppose what only comes into being through indimergence.

This explains why every attempt to model the transition between quantum mechanics and relativity theory by means of scales, limit cases, or continuous approximations necessarily fails. Such attempts operate with precisely those concepts—time, process, state—whose validity is only grounded through the transition itself.

The transition is therefore not unknown, but uncategorizable within the means with which physics operates. It is not a missing link between two theories, but a boundary structure at which it becomes visible under what conditions physical description is possible at all.

Section IV – Quantum Mechanics as a Description of Pre-Ontological Openness

Quantum mechanics is often understood as a theory of the microworld, as a description of small scales or fundamental building blocks. This reading falls short and misses the actual point of application of the theory. What is decisive is not the scale, but the status of that which is being described.

Quantum mechanics does not describe an unstable or incomplete version of classical objects. It describes a domain in which objectivity has not yet been coerced. Superposition is not a deficient state in comparison to classical facticity, but the expression of an openness that logically precedes object formation.

This openness, however, is not to be understood ontologically in the sense of an existing mode of being. It does not designate a mode of what *is*, but a pre-ontological structure of possibility from which objectivity can first emerge. In this sense, quantum mechanics does not describe a world in the strong sense, but provides a formal access to the conditions under which world-formation can occur at all.

Already in *Wave Function Collapse Is Not a Dynamical Process* (2026), it was shown that the wave function does not represent a hidden state of the world. Rather, it describes a space of what is possible. This space of possibility is neither epistemic nor subjective, but neither is it ontological in the classical sense. It is not a property of the world, but a precondition of its facticization.

Decisive here is the distinction between physical superposition and the pre-ontological space of possibility, as developed within the MNO framework. Superposition is a formal state within the theory. The space of possibility, by contrast, is the condition under which such states can be meaningfully described at all. Quantum mechanics operates within this framework without itself providing an ontological grounding of it.

In this sense, quantum mechanics operates structurally prior to indimergence. It describes openness without being able to explain the coercion toward facticity itself. Collapse therefore necessarily appears to it as a problem—not because it is unintelligible, but because it lies categorically outside what the theory can accomplish as a theory.

From this perspective, quantum mechanics is not an incomplete theory, but a deliberately limited one. It refrains from providing an ontology of object emergence in order to capture pre-ontological openness with mathematical precision. Precisely therein lies its strength—and at the same time the boundary at which it necessarily connects to other forms of description without being transferable into them.

Section V – Relativity Theory as a Description of Stabilized World Conditions

General relativity begins where quantum mechanics necessarily falls silent. It describes a world in which objectivity is already given: events, spacetime, causality. Its object is not the emergence of world, but its consistent persistence under conditions that are already fixed.

In relativity theory, time appears as a measurable quantity, space as a structured nexus, and gravitation as the curvature of stable relations. This description is empirically extraordinarily successful. It operates, however, within a framework in which world is already factual. The question of how this facticity itself comes about lies explicitly outside its methodological access.

As shown in *Time Difference Without Neutralization* (2025), relativity theory formally calculates time differences correctly, yet ontologically neutralizes these differences. Time appears there as a comparable variable within a relational system, not as an irreversible condition of world-formation. The past remains calculable, but structurally inconsequential; history becomes modelable, but not constitutive.

Relativity theory therefore does not describe the transition from possibility to facticity, but the stabilization of an already factual world. It is a theory of the conditions under which world can persist consistently, be distorted, and be coordinated. That it does not thematize openness, possibility, and the coercion toward facticity is not a shortcoming, but a methodological precondition of its formal precision.

In this sense, relativity theory is a theory after the shift of being. It silently presupposes that shift through which space, time, causality, and relation can first appear as stable magnitudes. Its strength lies precisely in this abstraction—and at the same time it marks the boundary of its ontological scope.

Section VI – Implication Without Mediation

Against this background, the relation between quantum mechanics and relativity theory can be determined with precision. It is neither a relation of derivation nor an incomplete approximation between two descriptions of the same level.

Quantum mechanics does not imply relativity theory in the sense of a derivation. Relativity theory does not follow from quantum mechanics by way of a limit case, a scale, or a successive approximation. Between the two, no path exists.

Instead, a different relation holds:

Ontological openness implies stability,
because world would not be viable without a coercion toward facticity.

Stabilized world implies openness,
because stability can arise only from the irreversible exclusion of possibility.

This relation is an implication, not a mediation. It is logical, not dynamical. It describes no movement from one state to another, but a structure of conditions under which world-formation can occur at all.

Indimergence marks the pre-ontological boundary act at which openness is excluded and facticity is coerced. *Shift of being* designates the consequence of this act: the irreversible change of the conditions under which further world-formation can take place. Both terms designate not transitions *within* the world, but conditions of its occurrence.

The apparent contradiction between quantum mechanics and relativity theory arises precisely where this relation of implication is falsely read as a problem of mediation. It is not a sign of theoretical incompleteness, but a structural marker indicating that two descriptions address different phases of the same pre-ontological framework, without being reducible to a shared process logic.

Section VII – Consequences

The framework developed here leads neither to a new physics nor to a unification of existing theories. It aims at something else: a precise demarcation of what physical description can accomplish—and what it necessarily presupposes.

Physics can formally describe ontological openness or model stabilized world conditions. It cannot, however, grasp the transition between the two as a process, as a dynamics, or as a mediable path without overstepping the categorial presuppositions of its own operation. Wherever it nevertheless attempts to do so, it projects its own concepts onto a level that is logically prior to them.

This insight does not weaken physics. It does not limit it epistemically, but clarifies its scope categorially. Physical theories are not incomplete because they fail to describe the transition from possibility to facticity, but because this transition cannot be an object of physical description.

Against this background, the conflict between quantum mechanics and relativity theory is not a deficit, but a structural marker. It indicates that world-formation itself does not fully unfold within physical theories, but presupposes conditions that these theories necessarily cannot retrieve.

Indimergence and *shift of being* designate precisely this boundary. They do not mark a gap in physical knowledge, but the pre-ontological conditions under which physical description becomes meaningful at all. The question therefore shifts away from a better mediation of theories toward the correct placement of what physics can accomplish—and of what lies logically prior to it.

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Information Without World
On the Limits of Additive Information Theories in Physics

DOI: **10.5281/zenodo.18045445**

Abstract

In contemporary physics, information-theoretic concepts are increasingly used as if information were an *indimergent* and additive quantity—that is, as if it could exist independently of world-integration, remain globally conserved, and be summed across the universe. This implicit assumption underlies claims such as “information is never lost,” computation-based cosmologies, and simulation-theoretic ontologies.

This paper argues that this constitutes a categorical overextension. Within the MNO approach (Minimal-Non-Object), information is reclassified as a *response quantity*: it arises exclusively where difference is emergent and stably integrated into world-relations. Information is *world-capable* only insofar as it is able to sustain stable, relational reality and remain causally effective within a shared world. Information may remain formally conserved without possessing this world-capability.

This distinction clarifies central paradoxes in black-hole physics and the quantum-mechanical measurement problem, and places principled limits on information-theoretic ontologies, without altering physical equations or introducing new entities.

This paper is situated in the context of:

Speed, T. (2025). MNO and Ontological Recurrence: A Non-Representational Account of Quantum Measurement and Conscious Experience (Version 1). Zenodo. https://doi.org/10.5281/zenodo.17913823

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1. Introduction: Information as an Ontological Shortcut

Information theory originates in the deliberately non-ontological, technically precise work of Claude Shannon. In contemporary physics, however, information is increasingly ontologically charged. Formulations such as "the universe computes" or "information is the most fundamental substrate of reality" implicitly treat information as a world-bearing quantity.

This paper neither questions the formal success of information-theoretic methods nor their physical relevance. It addresses exclusively a largely unspoken structural assumption:

That information is indimergent *(as an independently countable object-quantity)*—that is, that it exists independently of world-integration and is globally additive.

2. The Assumption of Indimergence

In many physical contexts, information is implicitly understood as a quantity that:

- exists independently of location and context,
- can be added across scales,
- possesses no intrinsic threshold of integration,
- "counts" even when it is no longer world-accessible.

In short:
Information is conceived as conservable even when world-integration fails.

This assumption enables strong formal statements (conservation, reversibility, unitarity), yet remains ontologically ungrounded.

3. MNO: Information as a Response Quantity

The MNO approach intervenes at this point without modifying the physical formalism. It proposes a conceptual reclassification:

Information is not an ontological substrate, but a response quantity.

That is:

- information arises only where difference is emergent
- and simultaneously stably integrated.

It follows:

Information presupposes world-stability; it cannot generate it.

Where integration fails, information may continue to exist formally, but it loses its world-capability.

By "world-capable," no additional physical property is meant, but rather the condition that information remains causally stable, relationally accessible, and recurrently sustainable within a shared physical world.

4. Black Holes: Conservation Without World

The so-called black hole information paradox displays this boundary with maximal clarity. The physical requirement of information conservation remains formally consistent. At the same time, the information is irreversibly withdrawn from any world-relation.

MNO therefore draws a strict distinction between:

- **formal conservation of information**
- **worldly sustainability of information**

Information can be conserved without being part of the world.

The paradox does not disappear as a result, but is instead placed into its proper categorical framework.

5. The Measurement Problem: Information Prior to Integration

An analogous structure appears in the quantum-mechanical measurement problem. Prior to measurement, information about states is formally describable. Only measurement, however, stabilizes world-relations.

From the MNO perspective, this is not a purely epistemic issue, but an integrative one:

Information prior to measurement is not world-capable, but merely formally expressible.

6. On the Limits of Additive Worldviews

Conceptions such as "the total information content of the universe" presuppose that information is globally additive and that the world would be fully integrable.

MNO contradicts this in a sober manner:

Emergence is not additive.
The world is not a storage device.

The universe is not a container for information, but a processual nexus of stabilization in which information arises only locally and conditionally.

"Not additive" does not mean here that emergent phenomena cannot possess local or extensive properties, but rather that emergence cannot be summed globally across breaks of integration.

7. Consequences for Simulation Theories

Simulation theories and computation-based ontologies remain meaningful within the scope of local models. They fail, however, where information itself is elevated to an ontological foundation.

Information can simulate a world, but it cannot ground one.

In this way, the scope of information-theoretic ontologies is precisely delimited without negating their operative strength.

8. Conclusion

This paper proposes no new physics. It alters no equations and introduces no new entities. It marks a boundary.

Information is a consequence of emergence, not its cause.
Physics can formally conserve information without conserving world.

Recognizing this boundary clarifies long-standing paradoxes and prevents a silent ontological overextension of information-theoretic concepts.

This paper understands itself as conceptual boundary work within physical theories, not as a competitor to them.

Black Holes as a Boundary Case for Emergence
An MNO-based Clarification of the Ontological Boundary of Physical World-Capability

*DOI: **10.5281/zenodo.17974324***

Abstract

Black holes are regarded as paradigmatic boundary objects of modern physics. They simultaneously mark limits of empirical accessibility, theoretical inconsistencies, and metaphysical projection surfaces. In popular as well as speculative discourses, they are frequently interpreted as manifestations of a "nothing," as cosmic singularities, or even as sources of emergent order.

This paper advances a deliberately countervailing thesis: black holes are not a case of application of emergence, but an extreme case of its failure.

On the basis of the MNO model (Minimal-Non-Object), which understands emergence not as an effect of energy or complexity but as the structural capacity to return into world-capable relation, black holes are analyzed as maximally indimergent systems. Their physical characteristics—event horizon, information paradox, observer-dependence, and the absence of reconstructable interior spaces—can be read consistently as expressions of a fully collapsed world-capability, without introducing new physical postulates.

The contribution does not aim to replace or extend existing astrophysical theories. Instead, it shows that the MNO model enables a conceptual clarification by strictly distinguishing physical conservation, informational coding, and relational accessibility. On this basis, black holes appear not as gateways to an ontological "nothing," but as boundary markers at which emergence, perspective, and recursive opening come to an end.

In this way, black holes function within this approach as a negative foil for theories of emergence: they sharpen the concept of emergence itself by showing under which structural conditions world-formation is no longer possible.

This paper stands in direct context with:

Speed, T. (2025). MNO and Ontological Recurrence: A Non-Representational Account of Quantum Measurement and Conscious Experience (Version 1). Zenodo. https://doi.org/10.5281/zenodo.17913823

1. Introduction: Black Holes Are Not Another Example

Black holes occupy a special position in contemporary physical and philosophical discourse. They are at once empirically well-substantiated astrophysical objects and theoretical boundary cases in which central assumptions of established models come under pressure. Event horizon, singularity, information paradox, and observer-dependence do not merely mark technical difficulties, but point to structural ruptures in the understanding of space, time, information, and causality.

Precisely because of this boundary position, black holes are frequently overextended. In popular, speculative, and in part also philosophical contexts, they function as projection surfaces for metaphysical meanings: as gateways to "nothing," as cosmic places of origin, as generators of new realities, or as physical analogies for consciousness. Such interpretations usually share an implicit assumption: that black holes, precisely because of their extremity, constitute a privileged site of emergence.

This paper intervenes at exactly this point—however, with a deliberately countervailing perspective. It argues that black holes are not to be understood as paradigmatic examples of emergence, but as extreme cases in which emergence structurally fails. They are not sites of new world-formation, but markers of where world-capability collapses.

The analysis proposed here is based on the MNO model (Minimal-Non-Object), which understands emergence not as a function of energy, complexity, or scale transitions, but as the structural capacity of a system to return into open, relational world-relations. Emergence, in this sense, is not an effect of intensive dynamics, but a criterion of world-capability: the capacity to sustain perspective, relation, and openness.

Against this background, black holes are not read as ontological manifestations of "nothing," but as maximally indimergent states. Their well-described physical properties—the causal closure through the event horizon, the inaccessibility of the interior, the reduction of external describability to a few parameters, as well as the problematic status of information—can be interpreted consistently as expressions of a complete condensation without a return path.

The explicit aim of this contribution is not to correct, replace, or supplement existing astrophysical theories by means of an alternative cosmology. Rather, it seeks to show that the MNO model allows for a conceptual sharpening by distinguishing where prevailing discourses tend to conflate levels: between physical conservation, informational coding, and relational accessibility. It is precisely in the case of black holes that it becomes visible that this distinction is not a philosophical add-on, but a necessity for correctly situating apparent paradoxes.

By treating black holes as boundary cases rather than as applications of emergence, they fulfill a precise methodological function in this context: they function as a negative foil. Through them, it becomes possible to show what emergence is not—and, at the same time, under which structural conditions emergence can become possible at all. In this sense, black holes do not contribute to an expansion of the MNO model, but to its conceptual disciplining.

2. Emergence, Indimergence, and World-Capability
(MNO in minimal form)

The concept of emergence is used inconsistently across different disciplines. In physics, it often denotes macroscopic properties that cannot be directly read off from microscopic equations. In systems theory, emergence is frequently associated with self-organization or nonlinearity, while in philosophical contexts, any form of novelty or surprise is sometimes regarded as emergent. This conceptual breadth is productive, but it leads to very different phenomena being subsumed under a single name.

The MNO model proposes a narrower, structurally more precise determination. Emergence is not defined here in terms of energy, complexity, or scale transitions, but in terms of the capacity of a system to return, after a phase of inner condensation, into open, relational world-relations. What is decisive is not that something new arises, but how this newness becomes world-capable.

To describe this dynamic, the MNO model distinguishes three structural phases: submergence, indimergence, and emergence. This triad does not describe a temporal sequence in a trivial sense, but a fundamental order of possible state-forms.

Submergence, in the MNO model, designates a state prior to the formation of object- and relation-structures. It is neither a physical initial state nor a temporal origin, but a structural situation of possibility. It is not an embeddedness within already existing fields, but the pre-relational openness from which such fields can first arise. In a submergent state, structure is present, but not yet located, not yet differentiated, not yet fixed as relation.

This primary submergence is not an emptiness in a negative sense, but a structure-bearing indeterminacy—a precondition for the very emergence of objects, relations, and fields. Only through indimergent condensation do locatable forms arise from this openness, which can then be embedded into relational contexts.

Submergence is therefore not to be equated with stability or order. It is the condition of possibility of order, not its execution.

Indimergence describes a phase of inner condensation. In indimergent states, systems withdraw structurally inward: degrees of freedom are reduced, relations are cut off or folded in, dynamics are concentrated. Indimergence is not necessarily destructive; it can be necessary in order to build up tension, stabilize form, or prepare transitions. It becomes problematic where it no longer possesses a return path.

Emergence, finally, does not merely denote the appearance of new properties, but the return of a system into world-capable relation under altered conditions. An emergent state is characterized by the fact that new structures are not only internally stable, but again possess connectivity: they can be carried, perceived, interpreted, or further developed. Emergence, in this sense, is always relational opening.

For a more precise account of this opening, the MNO model introduces the concept of world-capability. World-capability designates the structural possibility of a system to sustain perspective, relation, and openness simultaneously. A world-capable system is not necessarily conscious, living, or complex, but it is connectable: it can be part of a shared order without being completely closed off.

This determination has an important consequence: not every intensive dynamic, not every increase in complexity, and not every energy transformation is emergent. Processes can be highly dynamic, eventful, or spectacular without generating world-capability. Conversely, seemingly unspectacular processes can be highly emergent if they stabilize new relational orders.

Within this conceptual apparatus, emergence becomes a clear structural criterion. It is neither mystical nor arbitrary, but bound to a specific condition: the possibility of return from condensation into open relation. It is precisely at this point that the analysis of black holes will take up its work in what follows. They will not be measured by their energy, their gravitation, or their mathematical description, but by the question of whether, and in what form, they carry or interrupt world-capability.

3. What We Actually Know About Black Holes (and What We Do Not)

Black holes belong to the best-confirmed, yet at the same time most theoretically problematic objects of modern physics. Their existence is today well secured by a variety of independent observations: through the dynamics of stars in galactic centers, through gravitational-wave events in the mergers of compact objects, as well as through direct imaging of the accretion environments of supermassive black holes. In this sense, black holes are not hypothetical constructs, but empirically robust phenomena.

At the same time, their theoretical description is marked by fundamental uncertainties. These uncertainties do not primarily concern peripheral details, but the core of central physical concepts such as space, time, information, and observation. Black holes thus do not mark a mere technical challenge, but a structural boundary of the current physical apparatus of description.

A central element of this boundary is the event horizon. It does not constitute a material surface, but a causal separation line: beyond a certain radius, events are in principle no longer accessible to external observers. What is decisive here is that locally nothing singular happens at the event horizon. For a freely falling observer, the transition across the horizon—at least in idealized models—is not distinguished by an immediately perceptible physical event. The radical change does not concern local physics, but the global structure of causality.

The interior of a black hole thus eludes not only empirical measurement, but also consistent theoretical reconstruction. Classical solutions of general relativity lead to singularities at which curvature invariants diverge and the theory loses its own applicability. These singularities are, however, to be understood less as real physical objects than as markers of a model failure. The absence of a consistent description of the interior is not a temporary deficit, but an expression of a deeper incoherence between relativity theory and quantum physics.

Closely linked to this problem is the so-called information paradox. While quantum-mechanical principles suggest that information cannot be lost, it appears, in the complete collapse of matter into a black hole, to disappear irretrievably for external observers. Different approaches to resolution—such as holographic principles, firewalls, or alternative interior structures—attempt to resolve this contradiction, without a generally accepted consensus having been reached so far. What is noteworthy is that the paradox cannot be reduced solely to computational inconsistencies, but rests on a conceptual tension between conservation, accessibility, and observer-dependence.

Another frequent source of misunderstanding concerns the so-called jets of black holes. These highly energetic outflows are occasionally interpreted as expressions of inner dynamics or even as indications of an active interior. In fact, however, jets arise outside the event horizon, in the interplay of accretion disk, magnetic fields, and rotation. They provide no information about the state of the interior, but are boundary phenomena of an extreme gravitational environment.

In summary, it can be stated that black holes are physically well-defined objects with clearly describable external properties, yet at the same time sites of fundamental theoretical uncertainty. This uncertainty concerns less the question of whether black holes exist than what their interior means ontologically and how concepts such as information, observation, and causality are to be understood under extreme conditions. It is precisely at this point that the following analysis takes up its task—not with the claim of physically resolving these open questions, but in order to clarify which structural assumptions underlie them.

4. Black Holes as Maximally Indimergent Systems

From the physical starting point outlined in the previous section, a structural characterization of black holes can be derived that dispenses with additional assumptions. If black holes are considered not primarily as exotic objects, but as states of extreme condensation, their central property appears less as a "hole" than as a complete closure: causal, informational, and perspectival.

Within the framework of the MNO model, black holes can be described as maximally indimergent systems. Indimergence here does not simply denote high density or strong gravitation, but the structural withdrawal of all relational degrees of freedom into an enclosed interior state. The decisive feature of an indimergent system is not its intensity, but the absence of a return path into open relation.

Black holes fulfill this criterion in extreme form. With the event horizon, a boundary is established beyond which no interaction returns into the shared world-context. This boundary is not to be understood as a local wall, but as a structural severing of world-capability. The world, understood as a relational nexus of perspectives, does not end in the interior of the black hole, but at the impossibility of maintaining this nexus.

Particularly instructive in this context is the reduction of the external describability of black holes to a few parameters. Regardless of the diversity of the collapsed matter, black holes can be characterized by mass, angular momentum, and charge. This drastic simplification is not merely a computational result, but an expression of a far-reaching relational impoverishment. Different internal structures become indistinguishable from the perspective of the world because no relational degrees of freedom remain that could carry these differences.

What is crucial here is the clear distinction from the primary submergence of the MNO model. Black holes do not constitute a return to a pre-objective structure of possibility. They are not to be identified with the Minimal-Non-Object and are not to be understood as a productive void. Rather, they are states in which indimergent condensation fully dominates and all structural openness is suspended. The "interior" of a black hole is therefore not ontologically open, but structurally exhausted. Primary submergence is open because it precedes structural determination; maximal indimergence is exhausted because all difference has already collapsed.

This reading makes it possible to avoid common misunderstandings. Neither the singularity nor the event horizon marks a site of creative emergence. They rather designate the point at which emergence becomes impossible, because no relation returns that could carry a new world. The dynamics of black holes are, in this sense, intensive but unfruitful: they produce events, radiation, and energy dissipation, but no new viable orders.

The characterization of black holes as maximally indimergent systems thus shifts the focus of the analysis. Instead of searching for hidden internal structures or transformative potentials, it becomes clear that their theoretical significance lies precisely in negation. Black holes are not the source of new world-formation, but the boundary at which world-capability collapses. In this negative function, they become analytically fruitful for the MNO model: they mark the point at which the triad of submergence, indimergence, and emergence becomes asymmetric and the return into open relation is structurally excluded.

5. Why Black Holes Cannot Carry Emergence

The preceding analysis now permits an explicit application of the emergence criterion of the MNO model to black holes. What is decisive here is not whether black holes are dynamic, energy-rich, or powerful in their effects, but whether they fulfill the structural condition of emergence: the possibility of returning, after indimergent condensation, into open, relational world-relations.

Precisely this possibility is systematically excluded in the case of black holes. With the crossing of the event horizon, every feedback into the shared world-context comes to an end. Regardless of which physical processes may take place in the interior, the structural precondition for the emergence of new world-capable orders is lacking. Emergence does not merely presuppose change, but connectivity. Where no relation returns, no new world can arise. The term "maximally indimergent" does not designate an extreme value on a scale of physical condensation, but a categorial transition in which relational feedback is in principle excluded.

In this context, the extreme gravitation of black holes must also be read anew. Although gravitation is often understood in everyday language as a form of "attraction," it does not constitute relation in an ontological sense. Gravitation is not reciprocal openness, but a structural curvature that determines motion without enabling response. This distinction is meant conceptually, not physically; it does not aim at a redefinition of gravitation, but at a clarification of its ontological status in the context of emergence. The maximal gravitation of black holes is therefore not an expression of intensified relation, but the result of its complete loss. Where relational openness collapses, pure structural motion remains. The strength of gravitation thus marks not proximity, but the end of world-capability.

This diagnosis is not relativized by the fact that black holes exert significant effects on their surroundings. Accretion processes, radiation, and in particular relativistic jets show that black holes are not passive endpoints. They influence their cosmic environment in massive ways. Precisely here, however, a conceptual distinction is required that is frequently neglected in emergence discourse: the distinction between effect and emergence.

Jets of black holes arise outside the event horizon, in the interplay of accretion disk, magnetic fields, and rotation. They transport energy, particles, and under certain circumstances complex molecules into interstellar space. In astrophysics, it is therefore occasionally discussed whether such processes could contribute to the distribution of the chemical building blocks from which biological complexity may develop under suitable conditions. These hypotheses concern transport, excitation, and catalysis—but not emergence in the strict sense.

From an MNO perspective, jets are vectors, not carriers of emergence. They possess no recursive openness of their own, no binding to spaces of possibility, and no capacity to stabilize new relational interiors. Their effect is one-sidedly directed outward and fully dependent on the open systems they encounter. Should new orders arise in such downstream environments, emergence takes place there—not in the black hole and not in the jet itself.

It is precisely this boundary effect that confirms the characterization of black holes as maximally indimergent systems. Because no emergence is possible in the interior, tension is discharged at the boundary. Energy, matter, and momentum are released without giving rise to a new world-capable structure. The dynamics of black holes are, in this sense, intensive but structurally unfruitful. They generate events, not worlds.

This also makes visible a widespread misinterpretation. The idea that black holes could function as cosmic creators rests on an equation of intensity with productivity. The MNO model explicitly contradicts this equation. Emergence is not a measure of strength or reach, but of relational return-capability. Where this is absent, even the greatest effect remains external.

Black holes therefore do not carry emergence, even if they influence conditions under which emergence may become possible elsewhere. They are not sources of new world-formation, but generators of extreme boundary conditions. Their theoretical significance does not lie in a hidden creative potential, but in the clarity with which they show that emergence is bound to structural preconditions that are suspended by maximal indimergence.

6. Rereading the Information Problem: Conservation versus Relational Capability

The so-called information paradox of black holes is regarded as one of the most persistent problems in modern theoretical physics. In its classical form, it arises from the tension between two basic assumptions: the quantum-mechanical requirement that information must in principle be conserved, and the apparent inaccessibility of all information that disappears beyond the event horizon of a black hole. The conflict is often formulated as if physics were faced with the alternative of either relinquishing information or revising central principles of quantum mechanics.

What is striking, however, is that this formulation already contains a conceptual reduction. It tacitly assumes that information is a unitary quantity whose conservation and accessibility coincide. Precisely at this point, the MNO model allows for a clarifying distinction that alters the character of the paradox without anticipating a physical solution.

From an MNO perspective, a strict distinction must be made between the formal conservation of information and the relational capability of information. Formal conservation refers to the principled continued existence of state differences within a physical system, regardless of whether these differences remain accessible, reconstructable, or meaning-bearing. Relational capability, by contrast, describes the possibility that information is embedded in a world-capable context: that it can be read, interpreted, transmitted, or integrated into new orders.

The information paradox arises when these two levels are conflated. From the fact that information is no longer accessible to external observers, its ontological loss is hastily inferred. Conversely, from the formal requirement of its conservation it is derived that it must in some form continue to be world-effective. Both conclusions presuppose that conservation and world-capability are identical—an assumption that the MNO model explicitly rejects.

Against this background, black holes can be understood as systems in which information may be formally conserved, while its relational capability has fully collapsed. With the event horizon, not necessarily the existence of state differences comes to an end, but rather the possibility of introducing these differences into a shared world-context. Information is not destroyed, but structurally decoupled. It remains without relational perspectival capability.

This reading shifts the weight of the problem. The central riddle is no longer where the information is located or how it is encoded, but for whom it can still carry meaning. The paradox concerns less the ontology of information than its relation to the world. In a maximally indimergent system, this relation is suspended, without this necessarily resulting in a physical contradiction.

It is important to note that this shift does not constitute a physical solution in the narrow sense. It replaces neither holographic approaches nor quantum-gravitational models. Its contribution lies at the conceptual level: it makes visible that part of the paradoxical intensification results from an insufficient separation of ontological levels. By separating formal conservation from relational world-capability, the MNO model renders the information problem legible as a boundary phenomenon of world-relation.

In this sense, black holes appear not as places where information "disappears," but as systems in which information loses its world. This formulation is not a rhetorical intensification, but a structural diagnosis. It makes intelligible why attempts to resolve the information paradox solely through recoding, relocation, or mirroring of information repeatedly encounter limits: they address the question of conservation, not that of relation.

This once again confirms the function of black holes as a negative foil for emergence. Where information is no longer world-capable, no emergent order can arise. Black holes are not theoretically challenging because they contain too much information, but because they show that information without relation becomes ontologically empty.

7. Black Holes as a Negative Foil for Emergence

The preceding analysis suggests that black holes should be understood not as special cases of emergence, but as systematic counterexamples. It is precisely in this negative function that they gain theoretical significance beyond astrophysics. By showing under which conditions emergence becomes structurally impossible, they sharpen the concept of emergence itself.

Emergence, as determined in the MNO model, presupposes the capacity of a system to return, after phases of condensation, into open, relational world-relations. It requires not only dynamics, but recursive connectivity. Black holes mark the point at which this capacity is definitively suspended. They are not transitions, but end states with regard to world-capability.

This diagnosis allows for a precise distinction from other domains in which emergence is in fact observable. In biological systems, for example, condensation does not lead to closure, but to new differentiation. Morphogenetic processes build up tension without severing relation; on the contrary, they stabilize new interiors precisely through their embedding in open field-relations. Emergence here is not an effect of maximal control, but the result of sustained openness.

The same applies to cognitive and social systems. Consciousness, learning, or collective organization do not arise through enclosure, but through the capacity to maintain difference while at the same time enabling relational integration. Systems that close themselves completely inward lose this capacity. They can be highly active, respond and exert effects, without bringing forth a new world. In this sense, black holes share a structural logic with other maximally indimergent systems, even though their physical manifestation is unique.

The negative foil of black holes thus helps to avoid a widespread confusion: the equation of intensity with productivity. High energy, strong effects, or great reach are not sufficient conditions for emergence. What is decisive is whether a system can stabilize new relational orders. Black holes negate this question in a radical way.

It is precisely this negation that makes them epistemically fruitful for a theory of emergence. They show that emergence is not a universal property of complex systems, but remains bound to specific structural preconditions. Where these preconditions fall away, there remains effect without world, dynamics without perspective, and information without relation.

In this sense, black holes do not function within the framework of the MNO model as cosmic special cases, but as boundary markers. They mark the point at which the triad of submergence, indimergence, and emergence becomes asymmetric: indimergence dominates, submergence is no longer reachable, and emergence remains structurally excluded. This asymmetry is not pathological, but instructive. It allows emergence to be determined precisely through its absence, rather than being positively hypostatized.

At the same time, this opens the view toward other fields. Wherever systems operate under maximal enclosure—whether technical, institutional, or algorithmic—it can be asked whether emergence actually takes place or is merely simulated. Black holes provide no analogy in a superficial sense, but a boundary measure. They show how far indimergence can be driven without a new world emerging.

In this sense, the analysis of black holes does not permit the transfer of physical models to other systems, but it does permit the transfer of a structural criterion: the question of whether a return into world-capable relation is possible or structurally blocked.

8. Conclusion: What This Paper Does—and What It Does Not Do

This paper has not pursued the aim of making new astrophysical claims about black holes. It neither replaces established theories of general relativity or quantum physics, nor does it offer alternative models of accretion, jets, or interior dynamics. Nor is it claimed that the MNO model solves physical problems such as the information paradox in a technical sense. Such an objective would exceed the scope of the approach presented here.

Instead, the aim has been a conceptual clarification. Black holes were examined as boundary objects at which it becomes visible where prevailing concepts of emergence run up against their structural limits. Through the application of the MNO model, it could be shown that many of the paradoxes associated with black holes result less from physical inconsistencies than from a conflation of ontological levels—in particular, the equation of effect with emergence and of formal information conservation with relational world-capability.

The central thesis of this contribution therefore does not claim that black holes embody a new ontological principle, but that they provide a negative criterion. They mark the point at which emergence becomes structurally impossible, because maximal indimergence excludes any return into open relation. In this sense, black holes function not as sources of new world-formation, but as boundary markers of failed world-capability.

It is precisely this negative function that renders them epistemically fruitful for the MNO model. By showing what emergence is not, the concept of emergence itself is sharpened. Emergence no longer appears as unspecific novelty or as a by-product of high energy, but as a strictly relational category: the capacity of a system to re-enter a shared world-context after condensation.

Beyond astrophysics, this clarification opens connections to other fields without black holes being misconstrued as analogies or explanatory models. Wherever systems operate under maximal enclosure—technical, institutional, or algorithmic—it can be asked with similar conceptual care whether emergence actually takes place or is merely simulated. Black holes provide no measure of magnitude here, but a measure of boundary.

In this way, the paper makes a double contribution: it disciplines the application of the MNO model by clearly delimiting its scope, and at the same time sharpens its profile as a theory of the boundaries of emergence. Within this framework, black holes appear neither as cosmic metaphors nor as ontological origins, but as precise markers of where world ends because relational relation ends.

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Black Holes, Event Horizon, Information Problem

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Renormalization as a Boundary Operation in the Quantum Field Theory of the Standard Model

DOI: **10.5281/zenodo.18060365**

Abstract

Renormalization is one of the most successful technical procedures in modern physics. It renders quantum field theories predictive by systematically absorbing divergences into redefined parameters. Despite its practical indispensability, its conceptual status remains unclear: renormalization stabilizes calculations without explicitly stating which kind of boundary assumption is thereby enacted.

This paper argues that renormalization should not be understood primarily as a technical stopgap, but as an implicit boundary operation. Within the MNO (Minimal-Non-Object) approach, it is read as a formal response to integration limits: divergences appear not as mere calculational errors, but as signals of a formalism whose local predictive power can be secured only through active boundary management.

The proposed reading neither alters the mathematical formalism nor the practical application of renormalization. It does, however, make visible that the Standard Model operatively manages its own boundary conditions without explicitly conceptualizing them. Renormalization is thus reclassified as a stabilizing, but not world-constituting, operation.

Scope Statement

This paper:

- proposes no new physics,
- modifies no renormalization techniques,
- introduces no new degrees of freedom or entities,
- provides no additional empirical assumptions and no new predictions.

It understands itself as conceptual boundary work aimed at clarifying what renormalization does—and what it deliberately does not do.
Its concern is the conceptual status determination of an already established practice.

The MNO approach is not systematically introduced here, but is presupposed as a conceptual framework; a detailed exposition can be found in the reference list.

This paper claims no new insight into the mathematical structure of renormalization. Its contribution lies in the conceptual explication of a boundary logic that has long been operatively effective in the practice of effective field theories, but is rarely made explicit.

1. Introduction: The Paradoxical Success of Renormalization

Renormalization is regarded as one of the greatest successes of quantum field theory. Without it, many of the most precise predictions of modern physics would not be possible. At the same time, it belongs to the conceptually most uncomfortable elements of the Standard Model formalism: divergences arise, are removed, and the result works—without it being clear what status these divergences have with respect to formalism, scales, and reality.

In practice, this problem is often bypassed. Renormalization "works," and the question thus appears settled. This paper intervenes precisely at this point. It does not ask whether renormalization is legitimate, but which boundary assumption it operatively implements: which claims to global integrability are tacitly abandoned in order to preserve local predictive power?

2. Divergences as Boundary Phenomena

Divergences arise where integrations across scales can no longer be stably controlled within a given formalism—typically in the ultraviolet structure and in the handling of regulators at their limits. In the standard reading, they are treated either as artifacts of an incomplete formalism or as indications of new physics beyond certain energy scales.

The MNO approach proposes an alternative, minimalist reading:

Divergences are not errors, but boundary signals.

They mark points at which structure can no longer be treated as "straightforwardly integrable" without endangering the predictive power of the model.

3. Renormalization as Active Boundary Management

Renormalization responds to these boundary signals not by explaining divergences, but by formally neutralizing them: parameters are redefined, contributions are absorbed, and scales are organized in such a way that predictions remain stable within a given domain of validity.

From this perspective, renormalization is not an ontological operation, but a stabilizing one. It secures local physics by limiting claims to global integrability—it manages the point at which "the model" must cease to treat itself as ontologically closed.

Renormalization suppresses emergence beyond the stability threshold without negating it.

4. MNO: Renormalization Without Ontological Claim

Within the MNO approach, renormalization is not read as an indication of hidden entities or fundamental structures, but as a response operation to structural overload.

This means:

- renormalized quantities are not ontological carriers,
- but effective response parameters within a limited domain of validity.

This is not an instrumentalist argument in the sense of "merely fictitious," but a status determination: renormalized parameters are really effective within their conditions of stability, yet they do not ground a world ontology beyond those conditions.

Renormalization stabilizes physics; it does not constitute a world.

5. Relation to Effective Field Theory

Effective field theory has already operationally accepted this boundary logic. It explicitly relinquishes claims to global validity and works with clearly defined scale restrictions.

This paper does not read EFT as a merely pragmatic approximation, but as an implicit acknowledgment of an ontological boundary: EFT makes explicit what renormalization enacts implicitly—the separation between stable local describability and global ontological closure.

6. Consequences

The reading proposed here has no immediate calculational consequences. It does, however, alter the conceptual status of renormalization:

- Renormalization explains no reality.
- It stabilizes describability.
- It marks, without naming it, where object ontology ends.

In this way, a tacit category mistake is avoided: the equation of formal stability with ontological grounding. From this perspective, debates on naturalness and fine-tuning appear in part as symptoms of an inflated ontological demand placed on a formalism that is structurally designed around domains of validity.

7. Conclusion

Renormalization is not a deficiency of physics, but an indication of its boundary. It enables precise predictions by actively limiting claims to integration. The MNO approach renders this boundary operation visible without altering the physical formalism.

Renormalization stabilizes physics by suspending ontological closure.

This paper is situated in the context of:

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Speed, T. (2025). Orch-OR with Recurrence: A Minimal Dynamical Condition for When Objective Reductions Yield Conscious Experience (1 English). Zenodo. https://doi.org/10.5281/zenodo.17942531

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Speed, T. (2025). Seinsverschiebung (Shift of Being) as a Pre-Ontological Category - On the Incompatibility of Existence and Understanding in Modern Regimes of Stabilization (2 English). Zenodo. https://doi.org/10.5281/zenodo.18007628

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Vacuum Energy as a Residual Quantity On the Cosmological Constant as a Boundary Phenomenon of Physical Stabilization

DOI: **10.5281/zenodo.18061827**

Abstract

Vacuum energy occupies a peculiar dual role in modern physics. On the one hand, it is formally unavoidable: in quantum field–theoretical calculations it arises necessarily and enters the cosmological constant Λ. On the other hand, its calculated value is empirically catastrophically wrong, deviating by many orders of magnitude from the observed cosmological expansion. This tension is usually interpreted as a fine-tuning problem or as an indication of new physics.

This paper argues that the tension is due less to missing dynamics than to a categorical overextension. Within the MNO (Minimal-Non-Object) framework, vacuum energy is not read as an ontological energy quantity, but as a residual quantity of a formalism that counts emergent difference even though it is designed exclusively for stabilization. In this reading, the cosmological constant does not appear as a physical object, but as a formal remainder of a boundary operation within a formalism that can secure stability without delivering ontological closure.

The proposed reading alters neither the equations of general relativity nor the quantum field–theoretical formalism. It does, however, shift the conceptual status of Λ: from a mysterious energy of the vacuum to a marker of the boundary of what can be physically and stably measured. The cosmological constant problem is thus not solved, but categorically reclassified.

1. The Integration Gap and the Layers of Self-Stabilization

Vacuum energy does not mark a lack of knowledge or a missing physical object. Rather, it appears where a physical formalism encounters a structural integration gap: contributions are formally effective and computationally unavoidable, yet they cannot be integrated as stable constituents of a shared physical world.

At this boundary, physics does not respond with paralysis, but with self-stabilization. Divergent contributions are subtracted, redefined, or shifted into effective parameters. In this way, conceptual and formal layers gradually emerge that do not primarily describe additional aspects of the world, but instead secure the formalism's own capacity for description. These layers are not errors, but necessary artifacts of successful boundary work.

The quantities that arise in this process—vacuum energy, effective constants, renormalized contributions—are really effective within the formalism, yet they are not ontologically additive.

They do not constitute deeper layers of the world, but reflective layers of a model operating at its integration limit. In this sense, vacuum energy is to be read less as a physical substance than as a marker of a boundary at which formal stabilization takes the place of ontological closure.

2. Formal Unavoidability of Vacuum Energy

In quantum field theory, vacuum energy does not appear as an optional add-on, but as a formal consequence of the description itself. Fields are modeled as systems of degrees of freedom whose ground state is not identical to zero. Even in the lowest energy state, contributions remain that do not vanish computationally and enter sums over modes and scales.

These contributions are formally consistent and mathematically correct. They can neither be ignored nor arbitrarily removed without damaging the internal structure of the formalism. In this sense, vacuum energy is not a special case, but an expression of the same formal logic that also leads, in other contexts, to divergences and regularization procedures.

The problem does not arise at the level of calculation, but at the level of interpretation. When vacuum energy is read as an ontological energy of space itself, a tension emerges between formal necessity and empirical observation: the resulting value exceeds what is cosmologically measured by many orders of magnitude. This discrepancy is usually formulated as the cosmological constant problem or as a fine-tuning problem.

From the perspective advanced here, this tension is not an indication of hidden dynamics or a missing physical object. Rather, it marks the point at which a formally correct quantity is ontologically overextended beyond its conceptual domain of validity. The formal unavoidability of vacuum energy does not imply its world-capacity.

3. The Cosmological Constant as a Structural Residual Quantity

The cosmological constant Λ appears formally as a coupling term in the field equations of general relativity. In the established reading, it is often interpreted as the energy density of the vacuum and thus understood as a physical quantity with an ontological carrier. This reading directly links Λ to the contributions of vacuum energy that arise in quantum field theory.

From the perspective advanced here, it is precisely this linkage that is categorically problematic. It transfers a formally unavoidable quantity into an ontological context for which it is not designed. Λ then appears as a puzzling object: computationally compulsory, empirically extremely small, and ontologically difficult to integrate.

The MNO approach therefore proposes a different reading. The cosmological constant is not understood here as an energy object, but as a structural residual quantity of a boundary operation. By “residual quantity” no negligible computational remainder is meant, but rather a necessary marker of an integration boundary. Λ arises where a formalism counts contributions that are formally effective and computationally unavoidable, yet cannot be integrated as stable constituents of a shared physical world.

In this role, Λ fulfills a clearly delimited function. It stabilizes the large-scale description of the dynamics of the universe without providing an ontological explanation of the underlying contributions. Its empirical smallness does not appear, in this reading, as a fine-tuning miracle, but as an indication that what is being measured here is not an additive component of the world, but a boundary value of formal stabilization.

This reclassification alters neither the field equations nor cosmological models. It does, however, shift the conceptual status of the cosmological constant: away from the search for a hidden energy of space, and toward a reading in which Λ marks the boundary at which formal effectiveness can no longer be translated into ontological world-integration.

Here, "residual quantity" does not mean a lack of physical effectiveness, but a lack of ontological carrier.

4. Connection to Renormalization and Effective Field Theory

The reading of the cosmological constant proposed here does not stand in isolation, but fits into an already established practice of modern physics. Renormalization and the effective field theory approach in particular show that physical descriptions systematically operate with limited domains of validity, without thereby necessarily deriving ontological claims of totality.

Renormalization responds to divergences by absorbing formal contributions and securing the predictive power of the formalism within defined scales. Effective field theories go one step further by making this limitation explicit: they deliberately refrain from making statements about physics beyond a certain energy range and treat their parameters as scale-dependent, contextual quantities.

In this light, the cosmological constant can also be understood. Λ behaves structurally analogously to renormalized parameters: it is formally necessary, empirically determinable, and practically effective, without thereby claiming the status of a fundamental constituent of the world. Its role consists in stabilizing the large-scale description of cosmic dynamics, not in representing an ontological energy of space.

The decisive point here is not that Λ would be "merely effective," but that its effective status is systematically misconstrued. When the cosmological constant is read as an ontological quantity, the impression of a deep mystery inevitably arises. When it is instead understood as a residual quantity of a boundary operation, it fits seamlessly into the logic of effective field theories: as a parameter that guarantees stability without delivering ontological closure.

From this perspective, the cosmological constant problem appears less as a singular anomaly than as an expression of the same boundary structure already at work in renormalization and scale dependence. Λ is not a special case, but a cosmological manifestation of a more general principle of physical stabilization.

5. Consequences: Boundary Rather Than Mystery

The reclassification of the cosmological constant proposed here has no immediate computational or empirical consequences. It does, however, alter the conceptual framework within which the cosmological constant problem is usually discussed.

If Λ is understood as an ontological energy of the vacuum, its extreme smallness necessarily appears as a mystery. Fine-tuning arguments, anthropic explanations, or the search for new physical mechanisms then seem required in order to explain an apparently fundamental discrepancy. These strategies, however, presuppose that Λ must be read as an additive constituent of the world in the first place.

The perspective advanced here intervenes at an earlier point. It calls this ontological expectation itself into question. When Λ is understood as a residual quantity of a boundary operation, the problem shifts: what moves to the center is no longer the magnitude of the cosmological constant, but the implicit assumption that every formally arising quantity must also be ontologically fully integrable.

In this sense, the cosmological constant problem appears less as an unresolved physical mystery than as a symptom of a conceptual overextension. Physics provides, through Λ, a stable and empirically effective description of the large-scale dynamics of the universe. It does not, however, provide an ontology of the vacuum—and it need not do so in order to be successful.

This shift does not relieve physics of open questions, but it does relieve it of a tacit category error: the equation of formal stabilization with ontological grounding. In this reading, Λ does not mark a gap in physical knowledge, but a boundary of what can be integrated as world-capable within existing formalisms.

5.1 Residual Quantities and Operative Fractality

The reading of the cosmological constant proposed here is itself part of the very boundary logic it describes. It introduces no new ontology and generates no additional world-objects. Its effect consists instead in a shift of conceptual expectation: in suspending ontological closure at precisely those points where formal stabilization already suffices to secure physical describability.

In this sense, the reclassification of Λ is not an explanatory add-on, but an operative intervention at the level of conceptual formation. It does not act through the production of new entities, but through the opening of a conceptual gap in which existing practice becomes readable in a different way. This mode of effectiveness is not accidental, but structural: at the conceptual level it reiterates exactly the same boundary operation that also appears in renormalization, effective field theories, and information-theoretic boundary phenomena.

The cosmological constant thus appears not only as a residual quantity within the physical formalism, but at the same time as an indicator of a recursive structure: stability does not arise through ontological filling, but through the controlled suspension of closure claims. The efficacy of this perspective lies not in the introduction of new objects, but in the consistent legibility of a boundary at which formal physics remains operatively successful without ontologically closing the world.

6. Conclusion

This paper has introduced no new dynamics and has modified no existing theory. Instead, it has proposed a conceptual shift: the cosmological constant is read not as a mysterious energy of the vacuum, but as a residual quantity of a boundary operation within physical formalisms.

In this perspective, Λ does not appear as an indication of a hidden physical object, but as a marker of an integration boundary. It arises where formal contributions are computationally unavoidable, yet cannot be integrated as stable constituents of a shared physical world. The cosmological constant stabilizes the large-scale description of the universe without providing an ontology of the vacuum.

This reading does not solve the cosmological constant problem in a technical sense. It does, however, shift its status: away from the search for a missing substance and toward the insight into a structural boundary of physical description. The extreme discrepancy between formal expectation and empirical measurement thus appears not as a failure of physics, but as an indication of both the reach and the limits of its ontological claims.

In this sense, the cosmological constant fits into the same boundary logic already at work in renormalization, effective field theories, and information-theoretic paradoxes. Λ is not a special case, but a cosmological manifestation of the practice by which physics secures its own stability: through formal control at points where ontological closure is not possible.

This paper is situated in the context of:

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(The present text constitutes an interface translation into neurotypical academic discourse. This translation functions as an accessibility measure necessitated by dominant linguistic and epistemic conventions. It does not represent the native epistemic form of the research, but a communicative adaptation required for participation in standardized scholarly exchange.)

A more in-depth paper on the methodology can be found here:

Speed, T. (2025). Recursive Knowledge Instead of Additive Knowledge Accumulation - On the Epistemic Structure of Embodied, Neurodivergent Research (Version 1). Zenodo. https://doi.org/10.5281/zenodo.18054997

A paper providing an overview of the work can be found here:

Speed, T. (2026). Introduction to an Operator-Based Research Program - World, Work, Value, Consciousness – Structure and Boundary Questions Beyond Representational Models (Corpus

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