Foundational Structures of Mass, Time, and Energy Based on Finite Operations

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Abstract

This paper aims to clarify the conditions under which mass, time, and energy acquire physical meaning for agents limited to finite operations and observations. Rather than proposing new physical laws or asserting the existence of new particles, the work explicitly repositions the foundational structure and limits within which existing theories are valid, taking operability and finiteness as primary premises. Time is not assumed to be discrete but is reinterpreted as a continuous quantity with a minimal operationally distinguishable scale. Energy is treated not as an absolute quantity but as an observationally defined difference, allowing vacuum energy and divergence problems to be reorganized in terms of definitional domains. Furthermore, mass is interpreted as a collective effect of correlation sealing, and the concepts of a mass lattice and a correlation-based foundational quasi-particle are introduced to provide a unified description of the foundational structures of mass, time, and energy. The proposed framework does not negate established theories; instead, it clarifies their domains of applicability and provides a conceptual scaffold for repositioning unresolved problems as issues of definability rather than intractability.

1 Introduction: Finiteness as a Premise of Fundamental Physics

This chapter clarifies the implicit assumptions of infinity that have long been accepted in fundamental physics and explains how the finiteness of observation and operation constrains the very definition of physical quantities. The purpose and scope of this paper are also outlined.

1.1 Implicit Infinite Assumptions in Fundamental Physics

From classical mechanics to quantum theory and relativity, many theories have relied on infinite precision and continuous limits as calculational conveniences. Differentiability, continuous time, and infinitesimal operations are powerful tools for closing theoretical frameworks elegantly. However, actual observations and experiments are performed only under finite time, finite energy, and finite precision. This discrepancy does not invalidate the theories, but it obscures where the "meaning" of physical quantities is established.

1.2 The Fact of Finite Observation and Operation

In real measurements, finite temporal resolution, minimal energy differences, and limited information acquisition are unavoidable. For example, time measurements have finite response times, and energy is defined only as a difference. These are not merely technological limitations but arise from fundamental constraints related to causality and information theory. Finite operation theory takes this fact as its starting point and makes explicit the domain in which physical quantities are definable.

1.3 Purpose and Scope of This Paper

The purpose of this paper is not to propose new physical laws or to assert the existence of new particles. Instead, it aims to organize the foundational conditions under which mass, time, and energy acquire physical meaning under finite operations and observations, thereby repositioning the validity domain of existing theories. The goal is not to negate established theories but to indicate the horizon within which they can be safely applied.

2 Basic Framework of Finite Operation Theory

This chapter defines the core concepts of finite operation theory and clarifies how observation, operation, and evaluation jointly participate in the definition of physical quantities. The terminology and notation used in subsequent chapters are fixed here.

2.1 Definitions of Operation, Observation, and Evaluation

In finite operation theory, any physically meaningful quantity is defined through three stages: operation, observation, and evaluation. An operation is a finite action applied externally to a system, limited in time, space, and energy. Observation is the act of recording the system's response to an operation and necessarily has finite resolution. Evaluation is the process of comparing observational outcomes with reference standards and establishing quantities as differences or distinctions.

2.2 Fundamental Principle of Finite Operation Theory

The fundamental principle of finite operation theory can be summarized in a single statement: "A quantity that cannot be distinguished by finite operations is not defined as a physical quantity." This principle does not deny the usefulness of continuous limits or infinite precision as mathematical approximations. However, the physical meaning of quantities is secured only through finite operations. For example, if the difference between two energy states lies below the resolution of the measuring apparatus, they are operationally treated as the same state.

2.3 Distinguishing Infinite Limits from Inoperable Domains

In theoretical physics, infinite limits are often employed as convenient mathematical tools. Finite operation theory, however, clearly distinguishes infinite limits from inoperable domains. An infinite limit refers to a theoretical construction that can be approximated by finite operations, whereas an inoperable domain is one that cannot be distinguished or verified by any finite operation. In this paper, the latter is excluded from the domain of physical quantities, and its indefinability is treated as explicit information.

3 Foundational Structure of Time: Continuity and Operational Lower Bounds

This chapter redefines time not as a discrete quantity but as a continuous one with a minimal scale distinguishable through finite operations. This perspective allows an operational reinterpretation of Planck time and a reorganization of unresolved issues related to time.

3.1 Why Time Is Treated as a Continuous Quantity

In physical theories, time has been treated as a continuous quantity from classical mechanics to quantum theory. This continuity is essential for descriptions based on differential equations and causal structures. However, continuity does not imply infinite distinguishability. In finite operation theory, time is continuous but possesses a minimal scale that can be distinguished through operations.

3.2 Minimal Scale of Operable Time

Finite operations necessarily involve finite response times and information acquisition durations. If two time intervals, Δt_1 and Δt_2, cannot be distinguished by any operation, they are operationally regarded as identical. We define $\Delta t_{\min}$ as the smallest time interval that can be distinguished through operations. $\Delta t_{\min}$ does not imply a discrete unit of time; rather, it represents the boundary at which time differences begin to acquire operational meaning.

3.3 Operational Interpretation of Planck Time

Planck time, $t_P = (\hbar G/c^5)^{1/2}$, is often interpreted as the smallest unit of time. In the framework of finite operation theory, however, t_P is reinterpreted not as a claim of temporal discreteness but as a scale at which gravitational effects can no longer be neglected in operations. As the energy required for operations increases, gravitational influences become significant, and attempts to improve temporal resolution lead to self-inconsistencies. In this sense, t_P is positioned as a representative lower bound of operable time.

4 Foundational Structure of Energy: A Quantity Defined by Observation

This chapter reorganizes energy not as an absolute quantity but as a differential quantity defined through finite observation and operation. This perspective allows operational reinterpretation of energy lower bounds, vacuum energy, and divergence problems.

4.1 Conventional Definitions of Energy and Their Issues

In classical and quantum mechanics, energy plays a central role as a conserved quantity. However, the value of energy itself is not directly observed; it is always measured as a difference between states. Absolute values and reference points are often introduced for calculational convenience, which can obscure their correspondence with observation.

4.2 Energy as an Observationally Defined Difference

In finite operation theory, energy is defined as a state difference distinguishable through operations. If the energy difference ΔE between two states lies below the resolution of the measuring apparatus, they are operationally regarded as identical. We define $\Delta E_{\min}$ as the minimal energy difference that acquires physical meaning. $\Delta E_{\min}$ does not directly assert quantization of energy but marks the boundary at which energy differences become physically definable.

4.3 Repositioning Vacuum Energy and Divergence Problems

Vacuum energy and zero-point energy are known to produce divergences in theoretical treatments. From the perspective of finite operation theory, components that cannot be distinguished through observation or operation are not defined as physical quantities. Accordingly, absolute vacuum energy that is unobservable is repositioned not as a physical divergence but as a quantity outside the domain of definition. What remains physically meaningful are only the energy differences induced by operations and their observable effects.

5 Foundational Structure of Mass: Correlation Sealing and Mass Lattice

This chapter redefines mass not as an intrinsic property of particles but as a collective effect arising from sealed correlations. From this perspective, the foundational unit of mass, the mass lattice, and particle addresses are organized operationally.

5.1 Mass as Correlation Sealing

In conventional physics, mass has been treated as an intrinsic property of particles. In finite operation theory, however, mass is interpreted as the degree to which interaction-accessible correlations are rendered invisible from external operations. As correlations become increasingly sealed, the system responds less readily to external operations, which is observed as inertial and gravitational effects. Mass is thus not a cause but a consequence of correlation sealing.

5.2 Definition of the Correlation-Based Quasi-Particle (CBQP)

To describe correlation sealing in minimal units, we introduce the Correlation-Based Quasi-Particle (CBQP). CBQP does not assume a physically existing particle but represents the smallest operationally distinguishable event of correlation sealing. The foundational mass m_0 of a CBQP is not directly observable in isolation; it yields an effective mass only when considered as a collective. For a collection of N_C CBQPs, the effective mass is given by $M_{\text{eff}} = N_C m_0$.

5.3 Mass Lattice and Particle Addresses

CBQPs are not arranged continuously but are constrained to configurations permitted by correlation structure and operational accessibility. The set of such permissible configurations is referred to as the mass lattice. Positions on the mass lattice function as addresses of correlation states occupied by particles. Differences among particle species are determined not only by the total number of CBQPs but also by their configuration patterns. This structure is isomorphic to electron orbitals in the Bohr model and configuration rules in the periodic table, naturally accounting for the discrete appearance of mass.

6 Integration of Foundational Structures and Emergent Gravity

This chapter integrates the foundational structures of time, energy, and mass defined in previous chapters and organizes emergent gravity as a collective effect of correlation sealing. Gravity is not assumed as a fundamental interaction but is repositioned as a manifestation of spatial inhomogeneity in correlation visibility.

6.1 Mass Distribution as a Collection of CBQPs

The CBQPs introduced in Chapter 5 yield an effective mass distribution when distributed in space. Let $\rho_C(x)$ denote the number density of CBQPs at position x. The effective mass density is then given by $\rho_M(x) = m_0 \rho_C(x)$. Such a distribution implies spatial variation in the degree of correlation sealing, leading to position-dependent responsiveness to external operations.

6.2 Correlation Visibility and the Emergence of Gravity

In regions with strong correlation sealing, the amount of correlation information accessible from outside decreases. We introduce β as an indicator of correlation visibility, defined as the ratio between internal correlation content and externally accessible correlation content. When a spatial gradient of β exists, motion observed from outside appears as if an attractive force were acting. Thus, emergent gravity arises as a gradient of correlation visibility. In the weak-field limit, this description is consistent with the Newtonian form of gravity.

6.3 Repositioning Singularities and Divergences

Singularities in general relativity and divergences in field theories arise from assumptions of infinite density and infinite precision. From the standpoint of finite operation theory, these are interpreted not as physical breakdowns but as indicators of reaching inoperable domains. Black holes are redefined not by singularities but as boundary conditions where operational access to internal correlations becomes impossible.

7 Conclusion and Outlook: Choosing to Use Finiteness

This chapter provides a scientific summary of the entire paper and discusses the new foundational perspective offered by finite operation theory, along with future research directions it opens.

7.1 Scientific Summary

This work has redefined the fundamental physical quantities of time, energy, and mass within the framework of finite operation, observation, and evaluation. The common conclusion is that none of these quantities possess physical meaning as absolute entities; they acquire meaning only as differences distinguishable through finite operations. Time was repositioned as a continuous quantity with a minimal operationally meaningful scale. Energy was organized as an observationally defined difference, with vacuum energy and divergences placed outside the domain of definition. Mass was understood as a collective effect of correlation sealing, introducing structural concepts such as mass lattices and particle addresses. Integrating these results shows that gravity need not be postulated as a fundamental interaction but emerges naturally as a spatial gradient of correlation visibility.

7.2 Position of Finite Operation Theory

Finite operation theory does not negate existing theories. It functions as an operational foundation that can be superimposed on any theoretical description, much like a correction term. All experiments and observations are finite, and there exist no empirical results outside the scope of finite operation theory. In this sense, anything that would exceed finite operation theory must be a truly infinite phenomenon. The redefinitions proposed here clarify the domains of validity and breakdown of existing theories and reinterpret apparent failures not as inconsistencies but as entries into inoperable domains.

7.3 Dreams, Imagination, and Scientific Inquiry

The true aim of this paper is not to claim the feasibility of specific devices or technologies. Rather, it seeks to articulate structurally that future possibilities may exist and that human dreams, imagination, and curiosity remain far from exhausted. Technology has not yet reached the scale of human imagination. However, where this gap becomes explicit, a firm stepping stone appears. By confronting finiteness directly, concepts that once seemed impossible shift from being "unexplainable" to becoming "well-defined challenges for the next step." Finiteness is not a limitation but a simple fact of the universe. What is special is how humans choose to interpret and use it.

7.4 Future Outlook

Finite operation theory has the potential to influence a wide range of fields, including quantum gravity, cosmology, information theory, and measurement science. The day humanity begins to actively use finiteness will mark a true “Independence Day”—not independence from the unknown, but independence from assumptions of infinity. This paper is written as a first step toward advancing imagination into the future, carefully yet decisively.

Appendix A: Foundational Structure of Time and Its Difference from Existing Theories

This appendix organizes the differences between conventional definitions of time and its redefinition within finite operation theory. The structure is consistent with Chapter 3 of the main text.

A.1 Time in Existing Theories

In Newtonian mechanics, time is treated as an absolute quantity independent of space and common to all observers. In relativity, time is unified with space and redefined as a coordinate component dependent on the observer's state of motion. In quantum mechanics, time is not an operator but an externally given parameter.

All of these theories treat time as a continuous quantity, yet none explicitly define an operational lower bound on temporal distinguishability.

A.2 Redefinition of Time in Finite Operation Theory

Finite operation theory defines time as follows.

Definition A1: Time is the difference in change that is distinguishable through finite operations and observations.

This definition does not deny the continuity of time. What is denied is the implicit assumption that arbitrarily small time differences are physically distinguishable.

A.3 Operational Lower Bound of Time Δt_{min}

Any finite operation requires finite response time and energy. If two time intervals Δt_1 and Δt_2 cannot be distinguished by any operation, they are operationally regarded as identical.

We define Δt_{min} as the minimal time difference that acquires physical meaning:

$$\Delta t \geq \Delta t_{\text{min}}$$

Δt_{min} does not represent a discrete unit of time, but rather the boundary at which time differences become physically definable.

A.4 Relation to Planck Time (Numerical Example)

The Planck time is defined as

$$t_P = \sqrt{\frac{\hbar G}{c^5}} \approx 5.4 \times 10^{-44}\,\text{s}.$$

From the perspective of finite operation theory, t_P represents a characteristic scale below which attempts to improve temporal resolution induce gravitational self-contradiction.

This does not imply that time ceases to exist below this scale, but that it becomes unreadable by physical operations.

A.5 Intuitive Analogy

Consider an analog clock. The hand moves continuously, yet the observer has finite resolution. Extremely small time differences exist but cannot be read.

Finite operation theory does not claim that the clock hand stops, but rather that unreadable differences should not be treated as physical quantities.

A.6 Consistency and Difference from Existing Theories

The redefinition of time in finite operation theory is consistent with the continuity of relativistic spacetime and naturally explains the external parameter role of time in quantum mechanics.

The difference is summarized as follows: Existing theories assume time differences can be made arbitrarily small in principle. Finite operation theory asserts that physically meaningful time differences possess an operational lower bound.

This distinction provides a foundation for repositioning divergences and singularities as problems of definition domain rather than theoretical failure.

Appendix B: Foundational Structure of Energy and Its Difference from Existing Theories

This appendix organizes the differences between conventional definitions of energy and its redefinition within finite operation theory. The structure is consistent with Chapter 4 of the main text.

B.1 Energy in Existing Theories

In classical and quantum mechanics, energy plays a central role as a conserved quantity. However, the absolute value of energy itself is never directly observed; it is always measured as a difference between states. In quantum field theory, zero-point and vacuum energies are formally introduced, leading to divergence problems.

B.2 Redefinition of Energy in Finite Operation Theory

Finite operation theory defines energy as follows.

Definition B1: Energy is a state difference that is distinguishable through finite operations and observations.

Under this definition, unobservable absolute energy is not treated as a physical quantity. Only energy differences detectable through operations are physically meaningful.

B.3 Operational Lower Bound of Energy ΔE_{min}

Not every energy difference carries physical meaning. If an energy difference ΔE between two states lies below the resolution of the measuring apparatus, the states are operationally regarded as identical.

We define ΔE_{min} as the minimal energy difference that acquires physical meaning:

$$\Delta E \geq \Delta E_{\mathrm{min}}$$

ΔE_{min} does not directly assert quantization of energy, but marks the boundary at which energy differences become physically definable.

B.4 Relation to the Temporal Lower Bound (Numerical Example)

In finite operation theory, energy resolution is linked to the time required for an operation. If a lower bound Δt_{min} exists, the uncertainty relation gives

$$\Delta E_{\mathrm{min}} \approx \frac{\hbar}{\Delta t_{\mathrm{min}}}.$$

Taking Δt_{min} on the order of the Planck time t_P, ΔE_{min} acquires an order of magnitude close to the Planck energy.

B.5 Intuitive Analogy

Consider measuring temperature differences. Differences below the thermometer's resolution may exist but cannot be measured. Finite operation theory refrains from treating such differences as physical quantities.

Vacuum energy divergences are similarly interpreted as arising from treating unmeasurable absolute values as physical quantities.

B.6 Consistency and Difference from Existing Theories

Finite operation theory does not deny energy conservation or quantum computational methods. The difference is summarized as follows:

Existing theories allow formally defined absolute energies to generate problems. Finite operation theory excludes unobservable absolute quantities from the domain of definition.

This shift repositions vacuum energy and divergence problems as issues of definition rather than theoretical breakdown.

Appendix C: Foundational Structure of Mass and Its Difference from Existing Theories

This appendix organizes the differences between conventional definitions of mass and its redefinition within finite operation theory. The structure is consistent with Chapters 5 and 6 of the main text.

C.1 Mass in Existing Theories

In Newtonian mechanics, mass is defined as the source of inertia and gravity. In the Standard Model, mass is treated as an intrinsic particle parameter generated via the Higgs mechanism. In general relativity, mass and energy serve as sources of spacetime curvature.

While these theories assign numerical values to mass, they do not directly explain why those values take their specific magnitudes or why mass appears discretely.

C.2 Redefinition of Mass in Finite Operation Theory

Finite operation theory defines mass as follows.

Definition C1: Mass is the degree to which correlations become sealed and inaccessible to external operations.

Under this view, mass is not a causal intrinsic property of particles, but an operational consequence of correlation sealing.

C.3 Correlation-Based Quasi-Particles (CBQP) and Mathematical Expression

To represent correlation sealing in minimal units, we introduce the Correlation-Based Quasi-Particle (CBQP). CBQP does not assume a physically existing particle, but denotes the smallest operationally distinguishable correlation-sealing event.

Let m_0 denote the foundational mass of a CBQP. For a collection of N_C CBQPs, the effective mass is given by

$$M_{\text{eff}} = N_C m_0.$$

C.4 Mass Lattice and Particle Addresses

CBQPs are not arranged continuously, but are constrained to configurations permitted by correlation structure and operational accessibility. The set of such permissible configurations is referred to as the mass lattice.

Positions on the mass lattice function as addresses of correlation states occupied by particles. Differences among particle species arise not only from the number of CBQPs, but also from their configuration patterns.

This structure is isomorphic to electron orbitals in the Bohr model and the configuration rules of the periodic table, providing an intuitive explanation for the discrete appearance of mass.

C.5 Intuitive Analogy

The mass lattice can be compared to address allocation in memory space. Even with identical capacity, different configurations yield different functions. Likewise, particles with the same number of CBQPs can exhibit different properties depending on their configuration.

Mass depends not on how much is packed, but on how correlations are sealed and arranged.

C.6 Consistency and Difference from Existing Theories

Finite operation theory does not negate the Standard Model or general relativity. The Higgs mechanism can be reinterpreted as a specific implementation of correlation sealing. Mass-energy in general relativity is consistent with emergent gravity arising from gradients of correlation visibility.

The difference is summarized as follows: Existing theories treat mass as a given parameter. Finite operation theory explains mass as a collective correlation-sealing structure.

This shift repositions the origin and discreteness of mass as structural problems rather than unexplained assumptions.

Appendix D: Falsifiability, Limitations, and Domain of Applicability

This appendix clarifies the falsifiability, theoretical limitations, and domain of applicability of finite operation theory. Its structure is consistent with the main text and Appendices A–C.

D.1 Assumptions and Domain of Applicability

Finite operation theory is applicable under the following assumptions:

(1) All physical operations, observations, and evaluations are finite. (2) Operations requiring infinite precision, infinite time, or infinite energy are physically unrealizable. (3) The physical meaning of quantities depends on their distinguishability through operations.

If domains exist where these assumptions are violated, the applicability of finite operation theory is not justified. The theory is valid only within domains where finite operations are well-defined.

D.2 Explicit Falsifiability

Finite operation theory is falsifiable if any of the following conditions are demonstrated experimentally or theoretically:

(1) Finite operations consistently distinguish quantities below the operational lower bounds defined in the main text ($\Delta t_{\min}$, $\Delta E_{\min}$, m_0, etc.). (2) Infinite-precision measurements or operations are realized without inducing gravitational self-contradiction or correlation-sealing effects. (3) Absolute quantities deemed unobservable are reproducibly observed through finite operations.

These constitute principled falsification criteria and are currently inconsistent with established physical theories.

D.3 Domains Not Addressed

Finite operation theory does not directly address the following issues:

(1) Ontological existence of truly infinite phenomena or structures. (2) Ontological origins of observers or agents performing operations. (3) Completeness or truth of mathematical and logical systems themselves.

These issues lie beyond the operational scope of physics and are delegated to philosophy or mathematics.

D.4 Limitations in Relation to Existing Theories

Finite operation theory does not aim to replace existing theories. The Standard Model, general relativity, and quantum mechanics remain valid within their respective domains.

The theory provides an auxiliary framework that reinterprets divergences and singularities not as failures of theory but as indicators of reaching inoperable domains.

D.5 Open Problems and Delegation to Future Research

This work explicitly leaves the following issues unresolved:

(1) Concrete physical implementations of correlation-based quasi-particles (CBQP). (2) Dynamical equations governing the correlation visibility parameter β. (3) Complete correspondence between mass lattices and existing particle classifications.

These are not deficiencies of the present framework, but problems to be addressed by future theoretical and experimental research building upon finite operation theory.

This appendix demonstrates that finite operation theory is not a closed system, but an open operational language designed to invite falsification, extension, and refinement.