A Proposal of a Cosmological Model Based on Finite Operational Theory

An Operational Study on the Beginning and the End of the Universe

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Abstract

This study aims to reorganize the initial conditions and the final state in cosmology from an operational perspective, namely, the conditions under which finite observation, evaluation, and operation are possible, without relying on specific dynamical assumptions or the introduction of new particles. Based on the framework of finite operational theory, we take as a starting point the requirement that mass must be definable as a spatially sealed correlation. We show that spatial expansion, the emergence of time (temporal-direction sealing), and the formation of primordial black holes are not independent hypotheses but are necessarily required by the same consistency condition. The cosmological model proposed in this work does not reject standard cosmology and remains consistent with existing observational facts, while providing a conceptual framework in which the beginning and the end of the universe are understood not as events but as boundaries of definability.

1 Introduction

In this chapter, we clarify the motivation of this study, review implicit assumptions in conventional cosmology, and position the present work within the framework of finite operational theory.

1.1 Research Background

Modern cosmology, based on the Big Bang model, inflationary theory, and the ΛCDM framework combined with particle physics, has successfully explained a wide range of observational facts with high precision. However, these theoretical frameworks implicitly assume the following points:

- Space and time are defined from the outset.
- Mass and energy always possess well-defined meaning.
- Observation, evaluation, and description can be performed without limitation.

While these assumptions are practically effective, they become nontrivial in extreme situations such as the beginning or the end of the universe.

For example, when the universe was extremely small, it is not obvious whether mass or time could have been meaningfully defined. Such questions have rarely been addressed directly.

1.2 Problem Setting

The central question addressed in this study can be summarized as follows:

Under what conditions can the universe be defined as a universe that possesses mass, time, and causality?

The key point here is not to explain the beginning of the universe as a single physical event, but to reinterpret it as the establishment of definability conditions.

Using an everyday analogy, the concept of length only acquires meaning when a ruler exists. Similarly, mass and time acquire meaning only when conditions exist under which they can be measured and determined.

From this perspective, the beginning of the universe is not the moment of an explosion, but the moment when a measurable world became possible.

1.3 Position and Approach of This Study

To address this problem, this study adopts the standpoint of finite operational theory.

Finite operational theory takes as its starting point the principle that operations such as observation, evaluation, recording, and determination are fundamentally finite.

Within this framework, the following points are emphasized:

- Infinite precision measurements and infinite operational freedom are not assumed.
- Physical quantities are treated only when they are definable.
- Undefinable quantities are not regarded as physical entities.

In particular, this study employs an operational definition of mass as a spatially sealed correlation. Under this definition, the existence of mass requires a minimum spatial scale capable of confining correlations.

This minimum scale is referred to in this work as the mass-lattice spacing.

Although no detailed equations are introduced in this chapter, subsequent chapters will use the mass-lattice spacing as a starting point to demonstrate, in a step-by-step and consistent manner, why spatial expansion is required, why time emerges, and why primordial black holes are naturally formed.

2 Basic Framework of Finite Operational Theory

In this chapter, we summarize the fundamental concepts of finite operational theory that form the basis of this study. In particular, we clearly define the three key elements: operation, correlation, and determination, and show how they constrain the definability of physical quantities.

2.1 Definition of Finite Operational Theory

Finite operational theory is a theoretical standpoint that takes as its starting point the principle that operations such as observation, evaluation, recording, and determination are fundamentally finite in nature.

Here, the term "finite" does not merely refer to technological limitations. Rather, it is a principled assertion that infinite-precision measurements, infinite repetitions of operations, and the simultaneous handling of infinite degrees of freedom are physically impossible.

Using an everyday analogy, no matter how precise a ruler may be, it is impossible to read infinitely fine graduations. Similarly, nature itself is assumed to possess a structure that does not allow infinite operations.

2.2 Operations and Correlations

In finite operational theory, physical reality is not treated directly. Instead, correlations that have been determined through operations are taken as the fundamental units.

Here, a correlation refers to a relationship established between multiple degrees of freedom. Examples include the positional relationship between two objects or the correspondence of momenta between particles.

The crucial point is that the mere existence of a correlation is insufficient. Only when a correlation is evaluated and determined through an operation does it acquire physical meaning.

This can be expressed schematically as

$$C_{\text{exist}} \to C_{\text{defined}}. \tag{1}$$

Here, C_{exist} denotes an undetermined correlation, while C_{defined} represents a correlation that has been determined through an operation.

In finite operational theory, the total amount of C_{defined} is subject to a fundamental finiteness constraint.

2.3 Determination and Operational Limits

Determining correlations requires spatial and temporal resources. Finite operational theory does not assume that such resources are available without bound.

For example, if there is insufficient spatial separation, correlations cannot be isolated and determined. Likewise, without sufficient temporal allowance, evaluations cannot be completed.

These constraints directly affect the definability of physical quantities. A definable physical quantity is one that can be determined under finite operational resources.

In the following chapters, we make these operational limits explicit and demonstrate how fundamental concepts such as mass, space, and time are necessarily required.

3 Mass Lattice and Mass Definability

In this chapter, we clarify the conditions under which mass becomes definable within the framework of finite operational theory. In particular, we regard mass as a spatially sealed correlation and introduce the mass-lattice spacing as the minimum scale required for its realization.

3.1 Operational Definition of Mass

In finite operational theory, mass is not treated as an a priori attribute, but rather as a form of correlation that has been determined through operations.

In this study, mass M is defined as a state in which a certain amount of correlation is spatially localized and sealed. Conceptually, this can be expressed as

$$M \propto C_{\text{sealed}}, \tag{2}$$

where C_{sealed} denotes the amount of correlation confined within space in a form that cannot be freely exchanged with the exterior.

As an everyday analogy, consider a spring compressed inside a box. When the spring is prevented from expanding outward, energy is stored internally. Similarly, when correlations are spatially sealed, they behave as mass.

3.2 Introduction of Mass-Lattice Spacing

To spatially seal correlations, a minimum amount of spatial room is required. From the standpoint of finite operational theory, confining correlations within an arbitrarily small region is not permitted.

We therefore introduce the minimum spatial scale required for mass to be definable, referred to as the mass-lattice spacing Δx_M.

A necessary condition for mass to possess meaning is that the local spatial size L satisfies

$$L \geq \Delta x_M. \tag{3}$$

If this condition is not satisfied, correlations cannot be sealed within space, and the concept of mass itself fails to be established.

3.3 Universe Size and Mass Definability

Let us consider a situation, such as in the early universe, where the effective size of the universe is smaller than the mass-lattice spacing.

In this case, no correlation can obtain sufficient spatial room to be determined as mass. In other words, a situation arises in which the universe possesses no definable mass.

Although this may appear counterintuitive, it is a natural consequence of the finite operational principle that quantities which cannot be determined do not physically exist.

Therefore, for a universe in which mass is definable to be realized, the spatial size must exceed the mass-lattice spacing. This requirement directly leads to the necessity of spatial expansion, which will be discussed in the next chapter.

4 Requirement of Spatial Expansion

In this chapter, we demonstrate why the universe must undergo spatial expansion based on the mass-lattice condition introduced in Chapter 3. Here, spatial expansion is positioned not as a dynamical cause, but as a consistency condition required to restore mass definability.

4.1 Mass Non-Definability and Inconsistency

As shown in Chapter 3, for mass to be definable, the local spatial size L must satisfy

$$L \geq \Delta x_M. \tag{4}$$

In the early universe, if $L < \Delta x_M$, correlations cannot be sealed within space, and the physical quantity of mass fails to be established.

Under such conditions, quantities such as energy, momentum, and temperature, insofar as they presuppose mass, also lose their meaning. In other words, the consistency among physical quantities breaks down.

4.2 Spatial Expansion as a Resolution Mechanism

From an operational standpoint, there is only one way to resolve this inconsistency: to expand the spatial size L so that

$$L \geq \Delta x_M \tag{5}$$

is restored.

The crucial point is that this spatial expansion does not need to be caused by a force. In finite operational theory, spatial expansion is understood not as a dynamical cause, but as a condition adjustment required to satisfy definability.

Using an everyday analogy, if one cannot work on an overcrowded desk, the only solution is to enlarge the desk. Similarly, if space is insufficient to seal correlations, space must be expanded.

4.3 Repositioning Inflationary Behavior

In conventional cosmology, the rapid spatial expansion of the early universe has been explained by inflation. This study does not reject that phenomenon.

However, from the standpoint of finite operational theory, inflation is reinterpreted not as a consequence of a specific field or potential, but as a result required to restore mass definability.

Through this repositioning, questions such as why the expansion was rapid and why it was spatially uniform can be addressed in an operationally natural manner.

Thus, spatial expansion is shown to be not merely one possible option in the early universe, but a necessary condition for the realization of a universe that possesses mass.

5 Emergence of Time and Temporal-Direction Sealing

In this chapter, we explain why certain correlations remain undetermined even after spatial expansion and clarify how this situation necessitates the concept of time from the standpoint of finite operational theory. Here, time is defined not as an independent entity, but as an operational direction responsible for deferred determination.

5.1 Undetermined Correlations Remaining After Spatial Expansion

As shown in Chapter 4, spatial expansion is a necessary condition for resolving mass non-definability. However, even when space is sufficiently expanded, not all correlations can be determined simultaneously.

In finite operational theory, determination requires operational resources, which are finite. Consequently, there exists an upper bound on the number of correlations that can be determined at the same time.

As an everyday analogy, consider a situation in which many exams cannot be graded simultaneously. Although the answer sheets exist, the results are not determined until grading is completed. Similarly, correlations may exist but remain undetermined until operations are applied.

5.2 Concept of Temporal-Direction Sealing

To handle correlations that cannot be determined spatially, finite operational theory provides another option: deferring determination.

In this study, the operation of retaining spatially undetermined correlations by sealing them in the temporal direction is referred to as temporal-direction sealing.

Conceptually, this can be expressed as

$$C^{\text{(space)}}_{\text{undetermined}} \to C^{\text{(time)}}_{\text{sealed}}. \tag{6}$$

Here, time is an operational direction along which correlations are deferred for determination, rather than a pre-existing background.

By analogy, this is similar to placing documents into a pending folder to be processed later. Time functions as a structure for retaining undetermined correlations.

5.3 Establishment of the Arrow of Time

Once temporal-direction sealing is introduced, a natural asymmetry arises in the flow of determination. Undetermined correlations are sent toward the future, while determined correlations accumulate toward the past.

This asymmetry is recognized as the arrow of time. Importantly, it does not arise from asymmetry in dynamical laws.

From the standpoint of finite operational theory, the arrow of time originates from the operational direction of determination processing.

Thus, time is shown to be not an independently existing entity, but a concept that necessarily emerges to manage undetermined correlations under finite operational constraints.

6 Mass-Lattice Termination and Primordial Black Holes

In this chapter, we show that there exists an upper limit to the amount of correlation that can be spatially sealed, and we position primordial black holes as structures that emerge when this limit is reached. In this study, black holes are treated not as anomalous events, but as natural terminal structures within finite operational theory.

6.1 Concept of Mass-Lattice Termination

In Chapter 3, we showed that mass becomes definable only when correlations are spatially sealed. However, there exists an upper bound on the amount of correlation that can be sealed within a given spatial region.

From the standpoint of finite operational theory, it is not possible to confine arbitrarily large correlations within arbitrarily small regions. This constraint is a direct consequence of the finiteness of operational resources.

In this study, the maximum amount of correlation that can be sealed per unit space is referred to as mass-lattice termination.

Conceptually, the sealed correlation C_{sealed} must satisfy

$$C_{\text{sealed}} \le C_{\max}. \tag{7}$$

Only within this range can mass be stably defined.

6.2 Overdense States and Instability

In the early universe, as spatial expansion and the emergence of time proceed, regions with locally concentrated correlations may arise.

If, in a given region, the amount of sealed correlation attempts to exceed the mass-lattice termination $C_{\max}$, the state becomes operationally unstable.

As an everyday analogy, consider a storage medium into which data exceeding its capacity is written. Data beyond the limit cannot be retained in a normal form.

Similarly, when the amount of correlation exceeds what space can retain, the usual definition of mass breaks down.

6.3 Formation of Primordial Black Holes

Correlations that attempt to exceed the mass-lattice termination cannot be retained spatially in the usual manner. Within finite operational theory, such excess must be processed in a different form.

The structure that emerges as a result is a primordial black hole.

From the perspective of this study, a black hole is a state in which correlations are sealed in an extreme manner, forming an operational terminal structure beyond which further decomposition or determination is impossible.

Under this interpretation, primordial black holes are not accidental byproducts of the early universe, but entities that can be necessarily generated as long as a mass-lattice termination exists.

Thus, primordial black holes are naturally positioned as terminal structures of spatial correlation sealing within finite operational theory.

7 Redefinition of the Beginning and the End of the Universe

In this chapter, we integrate the finite operational framework introduced so far and redefine the beginning and the end of the universe not as physical events, but as boundaries of definability.

7.1 Redefinition of the Beginning of the Universe

In conventional cosmology, the beginning of the universe is often described as a specific physical event known as the Big Bang. From the standpoint of finite operational theory, however, a more fundamental question must be addressed beforehand.

That question is whether basic concepts such as mass, time, and causality were definable.

As shown in Chapters 3 and 4, mass becomes definable only when the spatial size exceeds the mass-lattice spacing. As shown in Chapter 5, time emerges to manage undetermined correlations.

Integrating these results, the beginning of the universe is understood not as the moment when something was created, but as the condition under which mass, time, and causality became simultaneously definable.

This represents a shift from viewing the beginning of the universe as a point-like event to viewing it as a boundary at which operational possibility was established.

7.2 Redefinition of the End of the Universe

Similarly, the end of the universe is redefined not as a specific terminal event, but as a boundary at which definability is lost.

From the perspective of finite operational theory, the following situations can be considered as candidates for the termination of the universe:

- Correlations become extremely diluted and cannot be determined.
- Correlations become excessively concentrated and exceed the mass-lattice termination.
- Temporal-direction sealing becomes saturated and determination processing halts.

In all cases, one or more of mass, time, and causality become undefinable.

Therefore, the end of the universe is understood not as a moment of destruction, but as the boundary beyond which the conditions required to describe a universe are lost.

7.3 Cosmological Implications

This redefinition allows several longstanding problems in cosmology to be reorganized from a new perspective.

For example, it becomes unnecessary to ask what exists before the beginning or after the end of the universe. Such regions are positioned as fundamentally undefinable.

This standpoint incorporates the limits of observation and theory not as weaknesses, but as constitutive principles of cosmology itself.

Thus, finite operational theory provides a framework in which the beginning and the end of the universe are repositioned from narrative events to operational boundaries.

8 Relation to Existing Cosmological Frameworks

In this chapter, we clarify how the cosmological model proposed within finite operational theory relates to major existing cosmological frameworks. The purpose here is not to reject existing theories, but to reposition them from an operational perspective.

8.1 Relation to the Standard Cosmological Model (ΛCDM)

The standard cosmological model, ΛCDM, has successfully explained large-scale structure, cosmic microwave background radiation, and primordial nucleosynthesis with high precision. Finite operational theory does not deny these successes.

From the standpoint of finite operational theory, ΛCDM is positioned as an effective theory that validly describes the universe after definability has been established. That is, it treats the behavior of the universe after mass, time, and causality have already become definable.

In this sense, finite operational theory provides the preconditions for ΛCDM rather than competing with it.

8.2 Relation to Inflationary Theory

Inflationary theory explains the horizon and flatness problems by assuming a rapid spatial expansion in the early universe. Finite operational theory acknowledges that these explanations are observationally effective.

However, finite operational theory reinterprets inflation not as being caused by a specific field or potential, but as a consequence of restoring mass definability.

Under this reinterpretation, the rapidity and spatial uniformity of expansion are naturally understood in operational terms.

8.3 Relation to Information-Theoretic Cosmology

In recent years, information-theoretic approaches to cosmology have been proposed, viewing the universe as an information-processing system. Finite operational theory shares several similarities with this direction.

However, in this study, information and entropy are treated not as abstract notions, but as quantities grounded in operational accessibility.

Specifically, information is defined as the amount of correlation that can be accessed and determined, while entropy is defined as the residual of correlations that could not be determined.

8.4 Positioning of the Present Study

Based on the above, the cosmological model derived from finite operational theory is not intended to replace existing cosmological theories, but to provide an operational foundation upon which they rest.

This study aims to respect observational facts and established theories while offering a systematic answer to the underlying question of why physical quantities are definable at all.

In this sense, finite operational theory functions not as a new competitor in cosmology, but as a foundational structure supporting cosmological theories.

9 Conclusion

In this paper, we reconstructed cosmology from the standpoint of finite operational theory and derived fundamental concepts such as space, time, mass, and causality not as a priori assumptions, but as consequences of the conditions under which definability is established.

The central claim of this study is that the universe is not an infinitely given stage, but a system structured by what can be defined under finite operational resources.

In Chapters 1 through 3, we showed that, due to the finiteness of operations and constraints on correlation determination, mass can be defined only when correlations are spatially sealed. This led to the introduction of the mass lattice and its characteristic spacing.

In Chapters 4 and 5, we demonstrated that spatial expansion is required to resolve mass non-definability, and that time emerges to manage the remaining undetermined correlations. Time was positioned not as a background entity, but as an operational direction responsible for deferred determination.

In Chapter 6, we introduced the mass-lattice termination as an upper bound on spatially sealable correlations, and showed that primordial black holes emerge necessarily as terminal structures.

In Chapter 7, these results were integrated to redefine the beginning and the end of the universe not as physical events, but as boundaries at which mass, time, and causality become definable or cease to be definable.

In Chapter 8, we clarified that the present framework does not compete with existing cosmological theories, but rather provides an operational foundation upon which they rest.

Taken together, the cosmological model based on finite operational theory shifts questions about the origin and fate of the universe from what happened to what can be defined.

As a limitation of this study, concrete numerical predictions and direct correspondence with observational quantities remain limited at present. Nevertheless, this framework provides a common operational basis for organizing issues related to initial conditions and singularities.

Future work includes clarifying the relationship between the mass-lattice spacing and known physical constants, connecting the framework to black hole thermodynamics, and integrating it with quantum information theory and gravitational theory.

In conclusion, finite operational theory offers a new cosmological perspective in which the universe is understood not as a given entity, but as the range over which conditions of definability are satisfied.

Appendix A: Formal Summary of the Finite-Operational Framework

This appendix provides a concise and reusable summary of the core elements of the cosmological model developed in this paper based on finite operational theory. The purpose here is not to introduce new claims, but to explicitly fix the concepts, definitions, and inequalities introduced in the main text as an operational backbone.

A.1 Finite Operation Assumption

The starting point of this study is the assumption that all physical descriptions are executed under finite operational resources.

Operations refer to actions such as observation, measurement, computation, recording, and determination that are required to define physical quantities. Since these resources are finite, there exists an upper bound on the quantities that can be determined simultaneously.

A.2 Correlation and Determination

Physical quantities are defined as correlations between a system and an observer (or measuring apparatus). In this study, correlation C is decomposed as

$$C = C_{\text{determined}} + C_{\text{undetermined}}. \tag{8}$$

Here, $C_{\text{determined}}$ denotes correlations fixed by operations, while $C_{\text{undetermined}}$ denotes correlations that remain unresolved.

Determination means that a correlation is fixed in an operationally accessible form.

A.3 Spatial Sealing and the Mass Lattice

When correlations are stably sealed within space, they become definable as mass.

For mass to be definable, the local spatial size L must satisfy the condition

$$L \geq \Delta x_M, \tag{9}$$

where Δx_M denotes the mass-lattice spacing.

If this condition is not satisfied, correlations cannot be stably sealed in space and mass becomes undefinable. The discrete structure introduced under this condition is referred to as the mass lattice.

A.4 Spatial Expansion and Temporal-Direction Sealing

If the initial condition satisfies $L < \Delta x_M$, the only way to restore operational consistency is to expand the spatial size L.

Correlations that cannot be determined even after spatial expansion are sealed along the temporal direction. Here, time is defined as an operational direction along which determination is deferred.

Conceptually, the following correspondence holds:

$$C^{(\text{space})}_{\text{undetermined}} \to C^{(\text{time})}_{\text{sealed}}. \tag{10}$$

Time is not a background entity, but a structure for managing undetermined correlations.

A.5 Mass-Lattice Termination and Operational Terminal Structures

There exists an upper bound on the amount of correlation that can be sealed within space. Let $C_{\max}$ denote the maximum sealable correlation per unit space. The stability condition is

$$C_{\text{sealed}} \leq C_{\max}. \tag{11}$$

If this bound is exceeded, the usual definition of mass breaks down and correlations are processed as operational terminal structures.

In this study, such terminal structures are reinterpreted as black holes. Black holes are not anomalies, but necessary terminal structures within finite operational theory.

The definitions and inequalities summarized above constitute the operational backbone of the entire paper, and all arguments in the main text are developed consistently within this framework.

Appendix B: Non-Contradiction with Established Theories

This appendix clarifies how the cosmological model proposed in this paper based on finite operational theory relates to major established physical and cosmological frameworks. The purpose here is not to negate or replace existing theories, but to make explicit the operational preconditions under which they are valid.

B.1 Relation to General Relativity

General relativity describes gravity as the geometric structure of spacetime. Finite operational theory does not deny this description.

From the standpoint of this study, general relativity is positioned as a theory that functions effectively in regimes where mass, time, and causality are already definable.

Finite operational theory addresses the conditions prior to the establishment of spacetime concepts or the boundary conditions under which spacetime becomes definable, while general relativity provides a continuous description thereafter.

In this sense, the two frameworks do not compete but instead play complementary roles.

B.2 Relation to Quantum Field Theory

Quantum field theory describes particles and interactions as excitations of quantum fields. Finite operational theory does not deny its successes.

Within finite operational theory, quantum field theory is regarded as an effective theory applicable after the establishment of the mass lattice and temporal-direction sealing.

While the present study reinterprets vacuum states and particle creation as processes of operational correlation determination, it does not replace standard computational formalisms.

B.3 Relation to Thermodynamics and Statistical Mechanics

In thermodynamics and statistical mechanics, entropy is defined in terms of microscopic degrees of freedom and probability distributions. Finite operational theory is not in contradiction with this definition.

In this study, entropy is interpreted as the residual of correlations that could not be determined. This constitutes an operational reinterpretation of statistical entropy and does not require numerical equivalence.

Accordingly, finite operational theory does not violate the second law of thermodynamics, but offers an alternative perspective on its conditions of validity.

B.4 Relation to the Standard Cosmological Model and Inflation

The standard cosmological model (ΛCDM) and inflationary theory are highly successful frameworks for explaining observational data.

Finite operational theory positions these theories as effective descriptions of the universe after definability has been established.

The present study does not deny inflation as a dynamical process caused by specific fields or potentials. Rather, it reinterprets inflation as a consequence of restoring mass definability.

Thus, finite operational theory coexists non-contradictorily with established theories and provides an operational framework that clarifies their underlying preconditions.

Appendix C: Illustrative Operational Reinterpretations

This appendix provides illustrative examples of how several well-known physical concepts can be reinterpreted within the finite operational framework introduced in this paper. The purpose here is not to propose new predictions or experimental tests, but to demonstrate how the abstract framework can be applied to concrete cases.

C.1 Reinterpretation of Black Holes

Within finite operational theory, black holes are understood as states in which correlations are sealed in an extreme manner. This interpretation does not deny the detailed dynamics of gravitational collapse, but rather characterizes the operational state reached as a result.

Inside a black hole, operations required to decompose or determine correlations become fundamentally impossible. Accordingly, a black hole is positioned as an operational terminal structure in which correlations that can no longer be determined are accumulated.

This interpretation allows the event horizon to be understood not as a boundary where information is lost, but as a boundary beyond which operations cannot reach.

C.2 Reinterpretation of Entropy

In thermodynamics and statistical mechanics, entropy is defined in terms of microscopic state counts and probability distributions. Finite operational theory does not deny this definition.

In this study, entropy is interpreted as the residual of correlations that could not be determined. That is, correlations left unresolved due to limited operational resources manifest as entropy.

Under this reinterpretation, entropy increase is understood not as mere disordering, but as a reflection of the limits of determination processing.

C.3 Reinterpretation of the Arrow of Time

The arrow of time is commonly explained in terms of entropy increase or special initial conditions. In finite operational theory, the arrow of time is understood as an asymmetry in determination processing.

Undetermined correlations are deferred toward the future, while determined correlations accumulate toward the past. This asymmetry in processing order gives rise to the perceived direction of time.

From this standpoint, time-reversal symmetric dynamical laws and the experienced temporal asymmetry can coexist without contradiction.

These reinterpretations demonstrate that finite operational theory reorganizes established physical concepts from an alternative perspective without disrupting their established meanings.