

A Structural Account of Temporal Ordering in Modern Physics

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Abstract

This paper develops a functional account of time across modern physics. Rather than treating time as a fundamental entity or as a purely metaphysical construct, the analysis proposes that temporal structure arises as an ordering parameter corresponding with the resolution of physical processes. By examining the role of time in special relativity, general relativity, and quantum mechanics, the paper shows that global temporal structure is not fundamental but emerges from locally resolved interactions and stable comparisons between physical states. This perspective clarifies why time remains indispensable in physical description while avoiding commitment to time as a primitive element of physical ontology.

1 Introduction

Most debates concerning time focus on whether time is fundamental, emergent, or relational [Barbour, 1999, Rovelli, 1991]. But such discussions typically investigate the flow of time for a set of events, while assuming that events are already available for ordering. Yet this assumption leaves an important question unanswered: what justifies the existence of an event in the first place? Events are commonly treated as rudimentary elements of temporal structure requiring no further explanation, but if events are the very entities whose ordering gives rise to temporal descriptions, then understanding what constitutes an event becomes not only necessary but also important in understanding time itself. The formalization of the flow of time cannot begin if events are assumed to exist.

A natural response is to regard events as basic constituents of physical reality. However, this assumption relocates the problem rather than solving it; a physical system may admit many possible configurations, understood as particular arrangements or states of the system. Yet a collection of configurations alone does not make up a collection of events. Configurations may exist as distinguishable possibilities without participating in any coherent structure. In such a case, there is no way to identify why one configuration should be treated as a distinct occurrence rather than merely another element within a set of events. Before events can be said to exist, the conditions that allow configurations to be distinguished, compared, and related must first be established.

A collection of configurations alone does not yet constitute a collection of events. Configurations may exist as distinct states of a system without participating in any well-defined structure. For a configuration to be identified as something more than an isolated state, it must be distinguishable from other configurations that permit comparison. Such a comparison depends on the availability of differences between configurations, without which configurations cannot be reliably differentiated. Since they are not differentiated, they do not participate in ordered relations. The problem of event formation, therefore, reduces to the conditions under which configurations become distinguishable and comparable.

Distinguishability is not absolute but depends upon the degree to which differences within a system can be resolved. A coarse-grained description may obscure structural differences that become apparent under finer-grained analysis[Gell-Mann and Hartle, 1993]. Resolution, therefore, does not gen-

erate new events but determines the precision with which distinctions between configurations can be identified. As the resolution of a description increases, a greater number of structural differences become available for coherent comparison, which strengthens the basis upon which configurations may participate in ordered relations. This paper argues that temporal ordering arises when stable distinguishable configurations admit coherent comparison. Events are not treated as primitive elements of temporal structure but as configurations identifiable within an ordered relational framework. Time functions not as the source of ordering but as the parameter tracking the resulting structure.

The remainder of this paper proceeds as follows. Section 2 examines the role of time in relativity and argues that modern physics undermines the notion of a single global temporal framework. Section 3 considers the treatment of time in quantum mechanics and highlights the dependence of physical description upon stable distinctions. Section 4 develops the concepts of distinguishability, comparison, and resolution, arguing that these provide the conditions under which configurations can participate in ordered relations. Section 5 addresses potential objections concerning event formation, ordering, and the status of temporal structure.

2 The Breakdown of Global Time

Classical physics treats time as a global, uniform parameter that orders events independently of the observer. On this view, temporal relations are absolute: if one event occurs before another, this ordering holds universally. Modern physics rejects this assumption. Both special and general relativity show that temporal structure is not globally defined but depends on the physical conditions under which it is measured. The result is a breakdown of the notion of a single, observer-independent temporal order.

In special relativity, this breakdown arises from the relativity of simultaneity. Observers in relative motion do not agree on whether spatially separated events occur at the same time, and this disagreement reflects the structure of spacetime rather than limitations of measurement [Einstein, 1905]. Temporal intervals likewise depend on the state of motion: clocks in relative motion register different elapsed durations. These features imply that temporal relations are frame-dependent, and no single ordering of events is preserved across all inertial observers.

This point is reinforced by the twin paradox. Two observers who begin at the same event and reunite after following different worldlines will generally measure different elapsed times. The asymmetry does not arise from subjective effects, but from the geometry of spacetime: proper time along distinct worldlines between the same events is not equal. Temporal duration is therefore path-dependent, and no unique measure of elapsed time can be assigned independently of the trajectory taken. General relativity extends this result by linking temporal structure directly to spacetime geometry. The elapsed time between events depends on the path through a curved spacetime, and gravitational fields alter the rate at which time passes [Einstein, 1916]. Clocks in stronger gravitational potentials register less elapsed time than those in weaker ones. Temporal structure is thus not only frame-dependent but dynamically shaped by physical conditions.

Taken together, these results rule out the idea of a global temporal framework. Temporal ordering is not universal, but local and path-dependent, and different observers may disagree on both the sequence and duration of events without error. What remains invariant is not time itself, but the spacetime structure within which temporal measurements are defined. Time, in modern physics, cannot be understood as a fundamental parameter that globally orders events, but must instead be regarded as a feature that emerges from the structure of physical processes.

This raises a further question: if temporal ordering is not globally defined, what conditions allow it to arise locally in a way that supports consistent comparison? Section 3 addresses this question in the context of quantum mechanics.

3 Time in Quantum Mechanics

While relativity undermines the idea of a global temporal framework, quantum mechanics introduces a different limitation. Temporal structure is not eliminated, but its role is reduced. In the standard formulation, time does not appear as an observable quantity, but as an external parameter governing the evolution of the system.

This is made explicit in the Schrödinger equation, which determines the time evolution of the quantum state [Griffiths, 2018]:

$$i\hbar\frac{\partial\Psi}{\partial t} = \hat{H}\Psi \tag{1}$$

Here, time enters as a parameter with respect to which the state evolves, while physical quantities such as position, momentum, and energy are represented by operators acting on the state. Unlike these quantities, time is not associated with an operator and is therefore not directly measurable within the theory [Dirac, 1981]. The formalism thus presupposes temporal structure to describe change, rather than deriving it from the properties of the system itself. Temporal ordering is not internal to the system, but imposed through the parameter that governs its evolution.

This limitation becomes explicit when considering the role of measurement. Before measurement, a quantum system is described by a superposition of possible outcomes, each associated with a probability amplitude. Such a description does not yield a determinate configuration that can be straightforwardly compared with others. Measurement, by contrast, produces a definite outcome, generating a record that can be related to other records. The transition from probabilistic description to definite outcome is not captured by unitary evolution alone. Processes such as decoherence explain how interactions with the environment suppress interference between components of the superposition, effectively stabilizing certain outcomes [Zurek, 2003].

The significance of this stabilization is structural. Only when outcomes are stabilized do they admit consistent identification across interactions, making comparison possible. Without such stable distinctions, there is no basis for relating states in a way that supports ordering. The Schrödinger equation provides a parameterized evolution, but in the absence of stable and distinguishable configurations, this evolution does not yield an ordering that can be physically realized.

Quantum mechanics, therefore, does not ground temporal ordering within the system itself. Instead, temporal structure becomes meaningful only under conditions in which probabilistic descriptions resolve into stable records. Time, in this context, functions not as an observable feature of the system, but as a parameter that tracks the ordering of states once they are stabilized. This shows that temporal ordering in quantum theory depends on the conditions under which configurations become sufficiently resolved to support comparison.

4 Time as Resolution

The preceding sections show that modern physical theories do not support a single, global notion of time. In relativity, temporal structure is local and path-dependent, while in quantum mechanics, time appears as an external parameter governing evolution rather than as an observable quantity [Einstein, 1905, 1916, Dirac, 1981]. These results undermine the view that time is a universal feature given independently of physical systems. The question, then, is how temporal ordering becomes available within physical description at all.

4.1 Configurations and Distinguishability

Any physical description assumes the existence of configurations. A configuration may be understood as a particular arrangement, state, or spatial organization of the components that make up a physical system. Configurations, in this sense, provide the most basic objects of physical description; the existence of configurations alone is not enough for the construction of a meaningful physical framework.

For a configuration to participate in description, it must be distinguishable from other configurations. Distinguishability refers to the presence of structural differences that allow one configuration to be identified as distinct from another; without such differences, a configuration cannot be differentiated and therefore cannot support comparison measurement or prediction. A collection of indistinguishable configurations is equivalent to a collection containing only a single identifiable configuration, since no differences exist where one configuration may be separated from another. Distinguishability, therefore, constitutes a necessary condition for physical description, yet distinguishability alone does not explain how configurations become events, nor does it explain how ordered relations arise from them. Additional conditions are required before configurations can participate in a coherent relational structure capable of supporting temporal ordering

4.2 Comparison and Event Formation

Distinguishability alone is not enough for event formation. Two configurations may differ from one another while remaining isolated within a collection

of possible states; in such cases, the existence of differences does not by itself provide a basis for physical description, since the configurations need not participate in any coherent structure. For distinguishability to become physically meaningful, distinctions must remain stable to permit comparison.

Comparison requires that structural differences between configurations remain sufficiently stable to support consistent differentiation; if distinctions fail to persist across interactions, configurations cannot be differentiated, and no clear relation can be established between them. Stability, therefore, provides the conditions under which distinguishability becomes usable within physical description; stable distinctions allow configurations to be related, compared, and identified as distinct occurrences within a broader structure[van Fraassen, 1980, Maudlin, 2012]. This motivates a new perspective on what an event is. Events need not be regarded as basic elements of physical reality. Rather, an event is a stable and distinguishable configuration whose differences are available for comparison within a relational framework. Stable and distinguishable configurations become events when their distinctions can participate in comparison. Events, therefore, emerge from more fundamental conditions involving distinguishability, stability, and comparison rather than existing independently of them.

4.3 Resolution and Ordered Relations

A collection of events may remain an unordered set unless relations can be established among them; the problem lies not merely in the existence of events, but in the conditions under which events form a relational structure that is coherent. This structure doesn't depend on distinguishability alone, but it requires distinctions to be available with precision to support reliable comparison.

Resolution is the degree to which structural distinctions already present within a system are available for stable comparison and participation in a relational structure. A coarse-grained description may hide distinctions that become visible under finer-grained analysis[Gell-Mann and Hartle, 1993]. To understand, let's take two descriptions belonging to the same physical system. One description may reveal broad features, while another reveals finer structural details, but it is important to note that the system remains unchanged, yet the number of available distinctions differs. Resolution does not generate new configurations or events, but determines the extent to which already existing distinctions are available for stable comparison within the

relational structure.

With higher resolution, more stable distinctions become accessible for comparison. Comparison is the process through which structural differences among distinguishable configurations become relationally meaningful. Comparison involves not only the recognition of structural differences but also the formation of relations among distinguishable configurations. Stable comparison instead places configurations within a network of relations, allowing the structural differences among configurations to be preserved within a coherent relational framework. Stable comparison establishes a relational structure among configurations by preserving the relations generated through their differences.

Ordering may be defined as the stable relational structure obtained through the comparison of distinguishable configurations. Ordering here is not used to denote a numerical ranking, sorted sequence, or temporal succession. Ordered relations consequently rely on the existence of consistent and adequately clarified distinctions. Events can only be recognized within a relational framework, and temporal ordering is achievable only when these conditions are satisfied. From this perspective, time does not create ordering, but it serves as a parameter that tracks ordering relations that arise from resolved physical configurations.

The importance of ordering can be demonstrated by examining structured and unstructured descriptions. Consider a pattern "ababab". Its relational structure is apparent through comparison of its constituent elements. On the other hand, an unordered collection containing the same symbols preserves the elements, but the relations among the elements are not the same, so the absence of relation structure removes the framework that made clear comparison meaningful. Similarly, physical systems may contain the same configurations while differing in the relational structure that connects them. Ordering concerns this relational structure rather than the configurations considered in isolation. Thus, ordering is not simply an extra element added to distinguish configurations, but it is the framework that maintains the relationships uncovered through comparison. In the absence of this structure, distinctions stay separate and fail to aid in forming a coherent physical description.

4.4 Time as a Structural Parameter

The earlier discussions in this paper imply that time ought not to be seen as the origin of order itself, but rather as a parameter that tracks order once it is established. Stable and distinguishable configurations permit comparison; comparison establishes relations among configurations, and ordering preserves these relations within a coherent framework. Consequently, time functions as a structural parameter that tracks an already established ordering among configurations rather than generating that ordering independently. This understanding aligns with the function of time in contemporary physics. Ordering, as developed in the previous section, refers to a non-temporal relational structure among distinguishable configurations. Temporal ordering arises when this structure is tracked through a parameter that preserves relations among physical processes.

In relativity, the measurements of time are local and vary based on the worldlines and conditions in which they are established [Einstein, 1905, 1916]. In quantum mechanics, time acts as an external variable that drives the progression of states and gains physical significance when consistent results allow for comparison [Dirac, 1981, Zurek, 2003, Schlosshauer, 2004]. In both scenarios, time does not function as a separate entity that organizes events, but rather as a measure that monitors ordering once the criteria for stable comparison are met.

In this perspective, temporal structure arises from the presence of stable and comparable configurations. Time should be viewed not as a basic constituent of reality itself, but as a structural factor emerging from organized relationships between defined physical processes. Temporal ordering, therefore, depends not on the existence of a universal temporal background but on the availability of stable, distinguishable, and sufficiently resolved configurations capable of participating in ordered relations.

5 Objection and Reply

5.1 Does Ordering Presuppose Time?

A possible objection that may arise in the framework that order presupposes, which is ordering, the key concept it aims to explain. If ordering suggests concepts such as prior or subsequent, then temporal structure has been assumed from the beginning rather than inferred. From this perspective, the

explanation of time would rely on the temporal relationships inherent in the ordering relation itself.

The objection rests on the assumption that ordering is inherently temporal. However, the framework proposed here introduces ordering as a structural relation among distinguishable configurations rather than as a temporal relation. The existence of stable and distinguishable configurations permits comparison, and comparison establishes among configurations. Ordering emerges from the organization of these relations into a coherent structure and does not require a before-and-after.

The framework, therefore, aims to explain temporal ordering in terms of non-temporal ordering structure rather than the reverse. Time is not the source of ordering but the parameter that tracks the ordering relations established among stable distinguishable configurations.

5.2 Why Does Comparison Require Ordering?

A second objection concerns the relationship between comparison and ordering in the framework. One may compare two configurations without placing them in a temporal succession. If comparison can occur independently of ordering, then the role of ordering is unclear, and why it should emerge from comparison at all.

This objection holds in the case of isolated comparisons. A single comparison between two configurations does not require ordering; the framework developed here is concerned not with isolated comparisons capable of supporting physical description. These networks necessitate that relationships between configurations are maintained and structured consistently, and in the absence of this organization, comparisons stay disjointed and fail to aid in creating a coherent depiction of a system.

It is the broader relational framework, rather than individual comparisons, that gives rise to a coherent, ordered structure. Ordering is therefore introduced as the minimal structure required to maintain relations across stable distinguishable configurations for comparison. Temporal ordering emerges when such relations are tracked in a consistent way across resolved configurations.

5.3 Is Resolution Observer-Dependent?

The status of resolution may appear problematic within the framework. The examples used throughout the paper, particularly those involving coarse-grained and fine-grained descriptions, may suggest that resolution depends upon observers, measurement devices, or methods of description. One might argue that temporal ordering becomes observer-dependent rather than a feature of the physical system itself.

Nevertheless, resolution is not presented as a means that establishes differences among configurations. Instead, it pertains to how many differences that already exist within a system can be recognized and maintained. A more detailed description might uncover structural variations that stay hidden in a coarse-grained description, yet the fundamental configurations are not produced by the process of observation.

The framework thus considers resolution as a factor influencing the recognition of distinctions instead of their presence. The relational framework between configurations is considered to exist apart from any specific observer, whereas resolution dictates the accuracy with which that framework can be articulated. Temporal ordering, therefore, relies on the presence of consistent and identifiable configurations instead of the subjective viewpoint of an observer. Resolution influences the sharpness with which ordering can be recognized, but it doesn't establish the ordering.

5.4 Are Events Emergent or Merely Identified?

A concluding objection pertains to the position of events within the structure. If configurations are already in place and resolution simply uncovers existing differences, then it might seem that events do not truly emerge. From this perspective, events would merely be pinpointed more accurately as resolution improves instead of emerging from any novel structural condition. This objection arises only if one assumes that events are the same as configurations.

The framework suggested here challenges this assumption. Configurations represent the fundamental states of a system, yet configurations by themselves do not form events. A set of configurations might exist independently without engaging in any unified relational framework. Eventhood necessitates further criteria, specifically distinguishability, stability, comparison, and ordered relationships between configurations. The difference lies

not in concealed events versus unveiled events, but rather in configurations and the events themselves. Although configurations can exist on their own, events occur only when configurations engage in a relational framework that allows for meaningful comparison. Eventhood is therefore not a fundamental aspect of configurations but rather a structural characteristic that arises in particular situations.

The framework, therefore, treats events as emergent rather than merely identified. Resolution may improve the precision with which events are recognized, but the existence of events depends upon the relational conditions that transform configurations into components of an ordered structure.

6 Conclusion

This paper argued that time does not function as a fundamental feature of physical reality, but as a structural parameter that arises within physical description. Relativity shows that temporal structure is not global but depends on the conditions under which it is measured, while quantum mechanics treats time as an external parameter governing evolution rather than an observable quantity. These results undermine the view of time as a universal background.

In response, the paper proposed that temporal ordering emerges from the conditions required for coherent representation. Once physical systems admit stable distinctions and comparison, ordering becomes necessary, and time serves to track this ordering. On this view, time is neither a basic element of reality nor an illusion, but a consequence of the way physical systems become describable. This account explains both the persistence and the non-fundamental status of time in modern physics. Time remains indispensable, not because it exists independently, but because it reflects the structure of relations that arise when physical processes are sufficiently resolved to support stable comparison.

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