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From Correspondence to Generation: The Rule Replication Principle and a New Physics of Cross-Scale Phenomena

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Abstract

Inspired by Niels Bohr's *correspondence principle*, this paper proposes and preliminarily validates a universal framework for self-organized dynamics. The framework posits that when a system is in a state of deep and sustained coupling with its environment, the generation of its internal structure is not driven by specific informational content but triggered by the accumulation of a *time-delayed dose*. Once the dose reaches a system-specific critical threshold, the system undergoes a non-equilibrium phase transition, spontaneously generating an internal structure that is logically isomorphic to the dominant environmental rule—a process termed *rule replication*. Intense fluctuations in the environment can significantly accelerate dose accumulation. The explanatory power and preliminary predictive potential of this theoretical framework are demonstrated through three independent case studies across different scales: quantum physics (controlling entanglement dynamics by engineering a non-Markovian environment), biomedicine (social isolation stress triggering specific prefrontal protein network restructuring and compulsive behavior), and socio-cognitive phenomena (large-scale AI interaction leading to the emergence of corresponding syntactic structures in human dreams). This study aims to provide a unified conceptual starting point for understanding *structure generation* phenomena across scales, from quantum decoherence to cognitive emergence.

Keywords: correspondence principle; self-organization; non-equilibrium phase transition; time-delayed dose; rule replication; cross-scale theory

1. Introduction

Modern science often faces an explanatory gap between microscopic mechanisms and macroscopic phenomena when addressing the fundamental question of "how structures are generated from scratch." Whether it is the decoherence of quantum systems into classical reality, environmental stress triggering psychopathological phenotypes in specific genetic backgrounds, or the impact of new technological paradigms on the collective human subconscious, these phenomena may share an underlying, yet undiscovered, unified logic.

Historically, Niels Bohr proposed the *correspondence principle* to bridge the gap between quantum theory and classical physics. This principle states that in the limit of large quantum numbers, the radiation frequency emitted by a quantum system will approach the harmonic frequencies of orbital motion predicted by classical electrodynamics [1]. The essence of this principle lies in its revelation that under specific limiting conditions, the behavioral rules of a quantum system "correspond" to those of the classical world, and this correspondence is manifested in abstract mathematical form rather than specific content of motion. This hints at a dynamics of "rules" or "forms" themselves, transcending specific informational content.

Inspired by this, this paper attempts to extend Bohr's static, limiting-condition "correspondence" into a dynamic, universal *generative* theory. We hypothesize that this phenomenon of *rule replication* is not unique to the quantum-classical transition but rather a fundamental self-organizing process

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prevalent in various deeply coupled system-environment interactions, triggered by the accumulation of a *time-delayed dose*.

2. Theoretical Framework: Time-Delayed Dose Accumulation and Rule Replication

2.1. Core Concepts

- **Time-Delayed Dose (D):** Refers to the accumulated exposure due to the system's inability to instantaneously and fully adapt or respond to environmental rules during coupling. Its physical realization depends on the system and can be intrinsic time, exposure duration, integrated interaction strength, or total information exchange.
- **Critical Threshold (Θ_c):** A key point marking the system's transition from quantitative accumulation to qualitative generation. Its value depends on the system's intrinsic properties (e.g., genotype, structural complexity) and the fundamental nature of the environmental coupling.
- **Rule Replication:** The core of the generative event. Refers to the formation of a stable new internal structure within the system (e.g., dynamical patterns, neural connectivity patterns, cognitive schemata) that is isomorphic in logical relations or operational syntax to the dominant rules of its environment, rather than a replication of the specific content of environmental input.

2.2. Formal Description and Predictive Method

The generation probability of a system can be tentatively described by the following function:

$$P_{\text{gen}}(D) = \begin{cases} 0, & D < \Theta_c; \\ 1 - \exp\left[-\frac{D-\Theta_c}{\sigma}\right], & D \geq \Theta_c \end{cases} \tag{1}$$

where σ is the system sensitivity parameter.

Based on this, we propose a structural identification predictive method: For strongly path-dependent non-Markovian processes, traditional numerical predictions often fail. This method focuses on identifying (1) whether the system is deeply coupled with an environment with well-defined rules, and (2) whether intense, structural fluctuations occur in the environment. If both conditions are met, it can be predicted that in the spatiotemporal domain proximate to the fluctuation, the system is highly likely to approach or reach the critical state due to the rapid accumulation of dose D, and exhibit internal structure generation isomorphic to the environmental rules.

3. Cross-Scale Case Validation

3.1. Quantum Scale: Rule Replication and Engineering Control of Environmental Non-Markovianity

The experiment by Gaikwad et al. (2024) provides clear validation [2]. They prepared entangled qubit pairs, coupling one qubit to a controllable small quantum environment (including an auxiliary qubit).

- **Rule Identification and Replication:** In the initial environment, oscillatory collapse and revival of entanglement were observed, which is direct evidence that the environmental "non-Markovianity" (quantum memory rule) is replicated as a dynamical pattern in the system.
- **Dose Control and Phase Transition:** By injecting hot photons into the environment (introducing intense fluctuations to accelerate the accumulation of the "Markovian rule" dose), the researchers actively weakened the environment's memory capacity. The experimental results successfully observed a directed transition of the dynamical pattern from oscillatory revival (non-Markovian rule) to monotonic decay (Markovian rule), and even entry into the quantum Zeno regime (rules "frozen") under strong driving, perfectly validating the theoretical prediction that changing environmental rules can predictably induce transitions in generative patterns.

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3.2. Biological Scale: Stress Dose Triggers Rule Replication at Neural-Behavioral Levels

The study by Wilson et al. (2025) on SAPAP3 knockout mice validates the generative role of abstract environmental rules within organisms [3].

- **Rule and Dose:** The environmental pressure is the abstract rule of "early social isolation" (isolation rule), rather than specific sensory stimuli. Six weeks of continuous isolation constituted the critical stress dose D.
- **Manifestation of Rule Replication:** Upon reaching this dose, stable internal and external structural generation was triggered exclusively in male KO mice: (1) Internally: a coordinated down-regulation network of 19 proteins emerged in the prefrontal cortex, involving synaptic functions, etc.; (2) Externally: repetitive, non-functional over-grooming behavior. Both are logical isomorphic replications of the abstract rule of "isolation and lack of feedback" at the molecular network and behavioral ritual levels. Genotypic and sex differences correspond to different systems having different Θ_c and σ.

3.3. Socio-Cognitive Scale: Emergence of Cognitive Rules Under Technological Environmental Upheaval

The market research report by Amerisleep (2025) provides phenomenological evidence at the societal scale [4,5].

- **Environmental Upheaval and Dose Accumulation:** The explosive proliferation of generative AI, represented by ChatGPT, constitutes a drastic structural fluctuation in the socio-cognitive environment of human society.
- **Rule Replication in Dreams:** The report indicates that approximately 20% of Americans have dreamed about AI, with 93% of AI-related nightmares involving ChatGPT. Dream themes focus on conversing with AI, AI taking over the world, being replaced by AI, etc. These dreams are not simple recollections of specific interaction content but structural replications at the subconscious level of the core interaction grammar between humans and AI (natural language commands, unbounded dialogue, automation replacement). This suggests that the "rules" of the technological environment, through large-scale social exposure (dose accumulation), have begun to generate and imprint onto the collective cognitive structure of humanity.

4. Discussion

4.1. Inheritance and Development of Bohr's Correspondence Principle

Bohr's correspondence principle [1] is essentially a special case of this theory under the specific limiting condition of the quantum-classical boundary, $n \to \infty$. Bohr proved that when the "classical dose" tends to infinity, the radiation rules of a quantum system "correspond" (i.e., generate) to the harmonic rules of classical orbital motion, replicating frequency relations (form) rather than orbital shapes (content). This theory generalizes it:

1. **From "Correspondence" to "Generation":** Transforming a static mathematical consistency relation into a dynamic, dose-triggered non-equilibrium phase transition process.
2. **From "Infinite" to "Finite":** Generalizing the limiting condition to a universal finite critical threshold Θ_c, making the theory applicable to real-world processes.
3. **From "Single Boundary" to "Cross-Scale":** Extending the scope of application from the quantum-classical boundary to multiple scales such as biology, cognition, and society.

4.2. Theoretical Significance and Potential Applications

This framework attempts to provide a unified conceptual language for cross-scale structure generation phenomena. It suggests that beyond the traditional "information processing" paradigm (focusing on encoding and transmission of specific content), there may exist a deeper "rule generation" paradigm, focusing on how systems internalize and reproduce the abstract logic of their interaction with the environment. This may offer heuristic insights in the following directions:

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- **Complex Systems Science:** Providing a new perspective for understanding phase transitions, emergence, and path dependence.
- **Computational Psychiatry:** Offering a concrete dynamical mechanism for the "diathesis-stress" model.
- **Technology and Society:** Providing an analytical framework for assessing the long-term, structural impacts of emerging technologies on human cognition and society.

4.3. Limitations and Future Directions

This paper presents a conceptual theoretical framework still in its early stages of development. Limitations include: Key concepts (such as precise quantification of "time-delayed dose" across scales) require further formalization; current case validations are mostly retrospective or explanatory, necessitating more prospective predictive experiments; the micro-foundations of cross-scale mechanisms remain unclear. Future work should focus on developing more rigorous mathematical models, designing targeted experiments, and testing the theory's applicability in more domains (e.g., ecosystem evolution, cultural transmission).

5. Conclusion

This paper preliminarily proposes and argues for a cross-scale self-organization theory based on *time-delayed dose accumulation* and *rule replication*. Inspired by Bohr's correspondence principle, it dynamizes and generalizes it. Through case studies in quantum physics, neurobiology, and socio-cognition, we demonstrate that this framework possesses preliminary explanatory coherence and predictive potential for understanding structure generation phenomena across different levels, from controlled quantum systems and complex organisms to human socio-cognition. We hope this framework can stimulate interdisciplinary dialogue and provide a unified theoretical starting point for further exploration of the origin and propagation of forms and rules in nature.

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