The Generative Dynamics Foundation of Computational Complexity: A Unifying and Degenerative Meta-Framework

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Abstract

This paper proposes a novel paradigm for measuring computational complexity based on the **Dynamic Generative Theory — Generative Complexity**. We argue that the traditional "step counting" based computational complexity theory is essentially an incomplete description of the dynamic generative process of "problem-solving". The true difficulty of a problem is inherent in the **generative work** required for the **correlation potential difference** embedded in the problem constraints to drive the deformation of the cognitive potential field. For the first time, we explicitly define that generative complexity is measured by the consumption flow of the generative element Ξ driven by the potential difference. Furthermore, we demonstrate that all mainstream complexity classes (P/NP, BPP, APX, IP, BQP) can be regarded as special cases of this framework after applying different **degeneration operations** (such as stripping determinism, ignoring process, losing directionality, misunderstanding quantumness). This framework not only provides a deeper dynamical foundation for understanding computational difficulty, but also offers a meta-theory that unifies and explains various computational paradigms from classical to quantum computing, and from exact to approximation algorithms.

Keywords: Generative Complexity; Dynamic Generative Theory; Correlation Potential Difference; Generative Element Ξ; Degeneration Operation; Meta-Framework

1 Introduction: From Step Counting to Generative Dynamics

Traditional computational complexity theory anchors the difficulty of a problem in the asymptotic growth of time or space steps required by an algorithm to solve it within a fixed problem space (e.g., P, NP classes). This "step counting" paradigm implicitly assumes a static presupposition: the problem and its solution space pre-exist, and solving is equivalent to searching in this space. The Dynamic Generative Theory [1] fundamentally challenges this presupposition, proposing that "solving" is actually a process in which the problem constraints and the solver's (human or machine) cognitive potential field, through

self-referential interaction, jointly and dynamically generate a solution framework, formulated as $NP = P +$ transfer function.

A core question follows: How to measure the essential difficulty of the "transfer function" — i.e., the dynamic generative process? We reject any measurement based on post-hoc statistics and insist that the difficulty must be inherent in the dynamical characteristics of the generative process itself. The central thesis of this paper is: the difficulty stems from the **correlation potential difference** carried by the constraints, and the intensity of the generative process can be characterized by the consumption rate of the fundamental action quantum of Dynamic Generative Theory — the **generative element** $\Xi := \hbar \cdot t_p$ — on the time scale.

More importantly, we will demonstrate that existing mainstream complexity classes can be obtained by **stripping away certain key dimensions** from this framework. This indicates that the generative complexity framework is a more fundamental **meta-framework** that unifies and explains the limitations and origins of existing complexity theories.

2 Core Framework: Formal Definition of Generative Complexity

2.1 Potential Field and Generative Element

Let the solver's cognitive state be a time-evolving, high-dimensional **potential field**, denoted as $\Psi(\Gamma, t)$. The global state of the field is described by the **historical depth** $H(t)$ and the **coherence degree** $C(t) = 1 - \exp(-H(t)/H_0)$. Any irreducible fundamental structural change in this field consumes a minimal unit of action, the generative element:

$$\Xi := \hbar \cdot t_p \tag{1}$$

2.2 Correlation Potential Difference and Potential Operator

A computational problem is defined by an ordered set of constraints $\mathcal{C} = \{c_1, c_2, ..., c_k\}$. Each constraint c_i is modeled as a **potential operator** $\hat{P}_i$ acting on the potential field. Its eigenvalue represents the specific **correlation potential difference** ΔP_i embedded in that constraint.

Key Definition (Potential Difference Intensity): The **instantaneous intensity** $I_i(t)$ of the potential operator $\hat{P}_i$ at time t is defined as the rate at which it causes the consumption of the generative element in the field Ψ:

$$I_i(t) \propto \left| \frac{\partial \Xi_{\text{consumed}}}{\partial t} \right|_{\hat{P}_i} \tag{2}$$

It directly quantifies the instantaneous magnitude of the "cognitive shaping force" exerted by the constraint on the field structure.

2.3 Generative Dynamics and Generative Complexity Measure

The evolution of the potential field follows a generative dynamics equation, driven by the potentials:

$$\frac{\partial \Psi}{\partial t} = \mathcal{D}[\Psi] + \sum_i I_i(t) \cdot \hat{P}_i[\Psi] \tag{3}$$

where $\mathcal{D}$ represents the intrinsic diffusion of the field, and the summation term represents the driving of each constraint. The solving process is the sequential injection of constraints, driving Ψ from the initial state Ψ_0 to deform into a stable final state Ψ_f (solution framework emergence).

The **generative complexity** $\mathcal{G}$ of a problem is defined as the total "generative action flow" during the entire generative process, i.e., the total cognitive work:

$$\mathcal{G} \propto \int_0^T \left(\sum_i I_i(t) \right) dt \tag{4}$$

It measures the intensity of the **shaping behavior itself**, rather than the number of search steps in a fixed space.

3 Unification and Degeneration: From Meta-Framework to Traditional Complexity Classes

The central argument of this section is: Traditional complexity classes are special cases of the generative complexity meta-framework when the cognitive process is incompletely understood, restricted in modeling, or misinterpreted, via specific **degeneration operations**. The following table outlines this degeneration map.

Table 1: The Degeneration Path from the Generative Complexity Meta-Framework to Traditional Complexity Classes

Degeneration Target	Key Degeneration Operation	Degenerated Form and Fundamental Limitation
BPP	Strip away the "deterministic attraction of endogenous correlation". Deny the existence of necessary resonance and guidance between the potential difference ΔP and the field structure Ψ. Retain "randomness" as a dynamical residue.	The generative process loses its intrinsic direction and can only rely on externally introduced randomness to simulate the release of potential. Its "probabilistic correctness" is merely a crude statistical imitation of the causal necessity of generative dynamics.
APX	Abandon the complete "generative process" perspective. No longer focus on the continuous deformation of the potential field $\Psi(t)$. Only focus on the static distance (approximation ratio) between the "result" and the target.	Reduced to a static snapshot comparison of the start and end points. It only measures the gap between the solidified imperfect form and the ideal form after the generative process is interrupted. This is an ex-post recognition of insufficient generative capability, measuring the wreckage rather than the process.
IP	Deprive the intrinsic directionality of "potential difference driving". Understand interaction as blind probing rather than resonance-guided.	The interaction between the verifier and the prover is weakened into a series of aimless, blind random challenges. The interaction loses the determinism based on the structural resonance of the field state Ψ that guides generation, degenerating into groping in the dark.
BQP	Misunderstand the role of "quantumness" in generation. Confine quantum features to tools for parallel path exploration and external interference. Use quantum features within the step-counting framework.	Although touching the quantum scale, it adheres to the old "search-interference" paradigm and fails to leap to the new "shaping-emergence" paradigm. It regards the answer as the result of interference, rather than the inevitable emergence of the framework as the attractor of the field's final state. This is the closest class that still falls short.
P/NP	Assume a completely static, pre-existing solution space. Completely ignore the cost of the "generative process" (transfer function).	Externalize all difficulty into the step difference between verification (P) and search (NP) in this fixed space. Completely ignores the more fundamental question of how the "solution space" itself is generated, i.e., the dynamical cost of the "transfer function".

4 Conclusion

The generative complexity meta-framework proposed in this paper re-anchors the essence of computational difficulty from static "step counting" to dynamic "generative dynamics". The core strength of this framework lies in its **unifying explanatory power**: it shows that the existing complex taxonomy of complexity classes can be logically derived by systematically stripping away certain key dimensions (such as determinism, process, directionality, or a correct quantum perspective) from this higher-dimensional, dynamical, and complete viewpoint.

This not only provides a new perspective for classical conundrums like P vs NP (recasting them as questions about whether the "generative process" can be efficiently simulated), but also points the way for future computational paradigms (such as quantum computing, brain-like computing): that is, how to design new computational primitives that can support and efficiently realize this kind of "potential difference driven generation". The generative complexity framework is not merely a new complexity class, but a meta-theory for understanding the limitations and origins of all computational paradigms.

References

[1] Chen, Z. *Dynamic Generative Theory: A Quantum Interpretation and Cosmological Unified Framework Based on the Chen Generative Element (Ξ).* Preprint on Zenodo. 2025.