

Five-Dimensional Systems Theory: From Speculation to Mathematics

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Abstract: Five-Dimensional Systems Theory (5DST) proposes a new worldview of systems: all things are systems characterized by the five-dimensional synergy of Boundary, Structure, Reserve, Direction, and Intensity, and the health of a system depends on its five-dimensional synergy degree. Its deep philosophical foundation is the **Principle of Relativity**: the essence of game and systemic competition lies not in the absolute strength of the subject, but in the relative proportional relationship among multiple subjects and dimensions. This paper further proposes the **Principle of Complementary Synergy**: homogeneous systems are difficult to form high-intensity synergistic gains, while heterogeneous complementary systems can give rise to high-order synergistic emergence effects. The article systematically expounds the basic worldview of Five-Dimensional Systems Theory, constructing its ontological, epistemological, and methodological systems within a unified theoretical framework. By introducing synergy coefficients as quantitative measurement tools, it realizes computable, evaluable, and dynamically traceable system synergy states. Cross-scale, multi-domain application analyses show that Five-Dimensional Systems Theory can provide modern systems science with a brand-new research paradigm that combines worldview innovation and quantitative operational tools.

Keywords: Five-Dimensional Systems Theory; Principle of Relativity; Principle of Complementary Synergy; Synergetics; Systems Science; Research Paradigm

1 Introduction: Systems Science Needs a New Worldview

The evolution of philosophy and science presents an overall thread from common origin in the mother body, disciplinary separation, and then interdisciplinary dialogue. Ancient Greek natural philosophy laid the ideological foundation for modern science; after

the scientific revolution, empirical natural science and speculative philosophy gradually diverged; since the 20th century, systems science and complexity science have developed rapidly, with core concepts such as holism, emergence, self-organization, and complex coupling becoming common issues for scientific modeling and philosophical reflection. The deep integration of the two fields has become an inevitable trend in complex science research.

There is a core tension in the current development of systems science: philosophical speculation can provide underlying insights but generally lacks quantitative operability, while mathematical and engineering models possess precise deductive capabilities but lack a unified meta-theoretical framework. General systems research repeatedly emphasizes the complexity and holistic emergence of systems, but when facing specific objects such as social organizations, engineering systems, and complex clusters, it still lacks universal diagnostic logic and structured intervention schemes. The continuous enrichment of descriptive theoretical systems and the long-term lack of implementable general analysis paradigms are key issues restricting the in-depth development of systems science.

The deeper core shortcoming is that systems science has not yet established a universally unified fundamental worldview. General Systems Theory defined the basic concepts of systems but did not form a standardized description system that can be used across domains[1]; Cybernetics revealed the operating mechanism of feedback regulation but did not establish the associative logic between feedback behavior and the overall steady state of the system[2]; Complexity Science focuses on the observation and induction of emergence phenomena but fails to provide judgment conditions and quantitative mechanisms for the generation of emergence[3]. Systems science in the new era not only needs to optimize research methods in subdivided fields but also needs to construct a unified theoretical paradigm that can penetrate natural systems, social systems, engineering systems, and cognitive systems.

Five-Dimensional Systems Theory is a systematic exploration responding to this theoretical need. The theory establishes the core proposition: all objective existence and complex organizations can be abstracted into a coupling and synergy system of five dimensions—Boundary, Structure, Reserve, Direction, and Intensity. The steady state and evolutionary capacity of a system are determined by the degree of five-dimensional matching, and the essence of system destabilization and degradation stems from dimensional mismatch and synergy failure. The bottom layer of the theory relies on the **Principle of Relativity**: the core determining factor of systemic competition, game, and evolution is not the absolute level of a single element but the relative proportional relationship among multiple elements and multiple subjects. This principle runs through the complete theoretical system: at the ontological level, it establishes the core position of

“existence is relationship”; at the epistemological level, it emphasizes the analytical logic of “cognition is comparison”; at the methodological level, it follows the governance idea of “intervention is tuning and matching”.

Meanwhile, this paper proposes the core foundational proposition—the **Principle of Complementary Synergy**: homogeneous system elements have overlapping functions and high substitutability, making it difficult to produce excess synergistic gains; heterogeneous complementary elements have dislocated functions and complementary advantages, capable of forming strong coupling synergy and overall emergence. The synergistic value of multiple subjects lies essentially in differentiated complementarity rather than homogeneous superposition. The advantages of collaborative wisdom among diverse groups in traditional governance precisely rely on the dislocation of capabilities, complementary experience, and functional division of different subjects, breaking through the capability boundaries of a single subject and forming a leap in overall effectiveness. The efficient operation of modern complex systems such as human-machine fusion, cluster collaboration, and large-scale organizational structures all take complementary synergy as the underlying mechanism, fully confirming that heterogeneous complementarity is the core condition for high-order synergistic emergence.

This paper proceeds from philosophical speculation, through axiomatic mathematical derivation, and finally settles on numerical empirical evidence, completely presenting the research path of “from speculation to mathematics.”

2 The Basic Worldview of Five-Dimensional Systems Theory

The theoretical core of Five-Dimensional Systems Theory is supported by three core propositions, along with two philosophical foundations—the Principle of Relativity and the Principle of Complementary Synergy—forming a self-consistent and complete system analysis framework.

2.1 Proposition 1: All Things Are Systems, and All Systems Are Five-Dimensional

All research objects, covering material entities, cognitive systems, social organizations, engineering structures, and civilizational clusters, can be decomposed into the coupling state and synergistic relationship of five dimensions: Boundary, Structure, Reserve, Direction, and Intensity. The five dimensions are not empirical arbitrary divisions but are derived from the essential needs of the system’s “existence—survival—evolution—

action”: Stable existence requires **Boundary** to distinguish the internal and external environments and scope of action; Long-term survival depends on stable **Structure** and schedulable **Reserve** resources; Continuous evolution must have a clear development **Direction**; Interaction with the outside world and internal operation rely on differentiated action **Intensity** to achieve. The five dimensions together constitute a universal analytical language for characterizing complex systems, possessing universality across scales and domains.

2.2 Ontological Axiom: To Exist Is to Be Five-Dimensional, and to Be Five-Dimensional Is to Exist

This paper directly cites the core axiom of Five-Dimensional Ontology[4]: the complete state of any real existing system is uniquely determined by its five-dimensional state vector; conversely, any five-dimensional state vector corresponds to a possible existence. Denoting the five-dimensional state of system \mathcal{S} as $\mathbf{s} = (B, S, R, D, I) \in (0, 1]^5$, then existence is equivalent to the **full-dimensional non-zoneness** of the five dimensions—all five dimensions must be greater than 0 (i.e., $B > 0, S > 0, R > 0, D > 0, I > 0$). If any dimension is zero, then the system does not hold in the ontological sense. This axiom lays the ontological foundation of Five-Dimensional Systems Theory.

2.3 Proposition 2: To Exist Is to Synergize, and to Be Healthy Is to Match

The steady state and development potential of a system do not depend on the extreme level of a single dimension but on the dynamic matching and synergistic equilibrium among multiple dimensions. A closed system with clear boundaries, if its internal structure is rigid and resource reserves are exhausted, will have its strong boundary constraints limit external resource interaction, accelerating system solidification; an organizational system with abundant resource reserves, if its development direction is vague and operating intensity is disordered, will cause excessive reserves to lead to resource internal friction and ineffective consumption; an engineering system with prominent action intensity, if its boundary control is vague and its own structure is fragile, will have its high-intensity load continuously amplify structural defects, inducing rapid destabilization.

To quantitatively characterize “synergy,” this paper defines the **synergy coefficient** κ as the product of the matching degrees of the five dimensions (see the axiomatic definition in Section 3.1). It is easy to prove: if any dimension deviates from the benchmark state, it will directly lead to the decay of the synergy coefficient κ , thereby changing the overall operating state of the system. Let the benchmark state of the system be \mathbf{s}_0 , and

the current state be \mathbf{s} . Define the cross-state synergy coefficient:

$$\kappa(\mathbf{s}, \mathbf{s}_0) = \prod_d \gamma_d(s_d, s_{0d})$$

If any dimension satisfies $s_d \neq s_{0d}$, then the corresponding dimensional matching degree γ_d changes, ultimately causing the overall change of the synergy coefficient. Thus it can be proved: the existence state of the system is strictly bound to the five-dimensional synergy coefficient, i.e., “to exist is to synergize.”

2.4 Proposition 3: The Process Reference Frame Principle

Five-dimensional analysis follows the rule of process limitation: the evaluation reference frame strictly serves the current research objective, and the temporary reference frame automatically becomes invalid after the process terminates. This principle effectively resolves the dimensional conflict problem of cross-scale evaluation in complex systems: the reserve indicators of engineering structures, the reserve resources of social organizations, and the reserve capabilities of civilizational systems do not have unified quantitative standards, and there is no need to construct a universal absolute reference system for the whole domain. Relying on the process-based temporary reference framework, the five dimensions maintain universal definitions, while specific indicators and quantification rules are customized in combination with the research scenario, enabling five-dimensional analysis to adapt to complex systems at different levels such as microscopic entities, mesoscopic organizations, and macroscopic civilizations.

2.5 The Principle of Relativity and the Principle of Complementary Synergy

The aforementioned core propositions form a complete theoretical system supported by two foundational principles.

Core connotation of the Principle of Relativity: The core determining factor of systemic competition, game, and evolution is the relative proportional relationship among multiple elements and multiple subjects, rather than the absolute level of a single element. In military confrontation, absolute parameters such as troop size and equipment level cannot alone determine victory or defeat; the core variables are the battlefield environment, logistical matching, tactical synergy, and relative situational relationships. In industrial competition, absolute indicators such as corporate asset scale and total production capacity do not directly determine the development ceiling; the relative pattern of industrial chain position, supply-demand matching, technological dislocation, and organizational synergy dominates long-term competitiveness. At the decision-making

cognition level, the absolute accumulation of individual knowledge stock and skill intensity needs to form a relative match with the problem scenario and task objective to ensure decision-making effectiveness. The Principle of Relativity is the underlying logic of Five-Dimensional Systems Theory and also the theoretical premise for quantitative tools such as synergy coefficients and relative matching degrees.

Core connotation of the Principle of Complementary Synergy: Homogeneous system elements have overlapping functions and high substitutability, making it difficult to produce excess synergistic gains; heterogeneous complementary elements have dislocated functions and complementary advantages, capable of forming strong coupling synergy and overall emergence. The synergistic value of multiple subjects lies essentially in differentiated complementarity rather than homogeneous superposition. The advantages of collaborative wisdom among diverse groups in traditional governance precisely rely on the dislocation of capabilities, complementary experience, and functional division of different subjects, breaking through the capability boundaries of a single subject and forming a leap in overall effectiveness. The efficient operation of modern complex systems such as human-machine fusion, cluster collaboration, and large-scale organizational structures all take complementary synergy as the underlying mechanism, fully confirming that heterogeneous complementarity is the core condition for high-order synergistic emergence.

2.6 The Effect of Reference Frame Changes on the Synergy Coefficient

Changes in the reference frame mainly affect the Direction dimension D (the direction description of vector physical quantities depends on the coordinate system selection) and can also indirectly affect relative quantification indicators such as Boundary B and Intensity I . Let the original directional matching degree of two systems be $\gamma_D = |\cos(\theta_1 - \theta_2)|$. After the reference frame rotates as a whole by $\Delta\theta$, both angles shift synchronously, the angle difference remains constant, and the relative matching degree between the two systems remains unchanged. The core effect of the reference frame is reflected in the **unidirectional matching relationship between the system and the task objective**: when evaluating the adaptability of a system relative to a fixed task objective, switching the reference frame will directly change the directional dimension matching degree, ultimately causing the synergy coefficient to fluctuate. Relying on the Process Reference Frame Principle, all synergy quantification analyses must be bound to clear research boundaries and evaluation objectives to ensure the objectivity and validity of the results.

The reference frame includes not only physical coordinate systems but also social norms, cultural habits, and institutional rules. For example, when multiple people sit around a table for a meal, the social norm defaults to “what is on others’ plates is not to be taken”—this is an intangible boundary defined by the social reference frame. If the reference frame changes (such as family gatherings or close friends), this boundary may disappear or relax. This shows that the choice of reference frame directly affects the matching degree γ_B of the Boundary dimension, thereby affecting the overall synergy coefficient κ . The Process Reference Frame Principle of Five-Dimensional Systems Theory precisely requires analysts to clarify the type of reference frame currently adopted.

2.7 Epistemological Paradigm: The Five-Dimensional Complementarity of Mathematical Formulas and Human Subjective Consciousness

The Principle of Complementary Synergy applies not only to natural systems and social organizations but also has profound manifestations at the epistemological level. Taking mathematical formulas (instrumental rationality) and human subjective consciousness (value rationality) as examples, both have natural dimensional gaps in the five dimensions, and after coupling and linkage, they achieve dimensional complementation, forming a complete closed loop of “knowing the world—transforming the world.”

Viewed separately, mathematical formulas have natural shortcomings in target direction and problem domain definition; human subjective consciousness has significant deficiencies in logical rigor and operational execution precision. The coupling of the two is not a simple superposition of five-dimensional vectors but generates an equivalent five-dimensional state of the joint system, achieving bidimensional complementation. This mechanism perfectly fits the dialectical logic of “practice—cognition—re-practice—recognition” in *On Practice*, providing an ontological explanation at the level of systems science for dialectical epistemology.

2.8 Complementarity Deficiency: The Starting Point of System Collapse

The Principle of Complementary Synergy has a reverse constraint mechanism: **the core starting point of system degradation, destabilization, and deconstruction is the rupture and imbalance of internal complementary relationships.** When the originally interdependent and functionally complementary units within a system experience problems such as homogeneous involution, collaborative fragmentation, and ad-

Table 1: Five-Dimensional Complementarity of Mathematical Formulas and Human Subjective Consciousness

Dimension	Mathematical Formulas (Instrumental Rationality)	Human Subjective Consciousness (Value Rationality)	Coupling Emergence
Boundary B	Deduction range limited by the axiomatic system	Can break formal boundaries and define the problem domain	Unification of cognitive domain and problem domain
Structure S	Logical structure is rigorous and formalizable	Conceptual structure is flexible and can be metaphorically associated	Complementarity of formal reasoning and intuitive leaps
Reserve R	Theorem library, algorithm library (stock knowledge)	Experience, intuition, imagination (generative resources)	Closed loop of knowledge retrieval and knowledge production
Direction D	Deduction direction determined by logical necessity	Value direction set by subjective purposiveness	Unification of “seeking truth” and “seeking goodness”
Intensity I	High-density symbolic operation, precise execution	High-intensity meaning attribution, risk decision-making	Compound of precision and decisiveness

vantage dissipation, the overall synergy level will continue to decline, gradually falling into disordered evolution. Minor dimensional mismatches will continuously accumulate in temporal evolution, successively eroding boundary stability, destroying structural integrity, consuming reserve resources, deviating development directions, and mismatching action intensity, forming a chain of defects that ultimately induces overall system destabilization. Routine dimensional tuning and complementary repair are the core guarantees for the long-term steady-state survival of complex systems.

Typical Case 1: Breakdown of Social Organization Synergy and Development Decline Small collaborative organizations relying on functional complementary division of labor operate stably. Once the core complementary architecture is dismantled, collaborative efficiency plummets, and a single subject cannot cover the complete business chain, ultimately falling into stagnation and decline.

Typical Case 2: Governance Structure Imbalance Crisis of Science and Technology Innovation Enterprises Science and technology innovation teams achieve high-speed development relying on the diverse complementarity of technology, strategy, operations, and market. The ideological split and misalignment of rights and responsibilities among core partners will directly destroy the complementary system. Even with technological and capital advantages, they will still rapidly fall into a business crisis.

Typical Case 3: Systemic Decline of Large-Scale Group Systems The common characteristic of the long-term decline of large industrial groups: strategic rigidity, homogeneous internal friction among departments, failure of complementary collaboration mechanisms, breaking of multi-dimensional synergy equilibrium, and gradual deconstruction and contraction under external shocks.

In summary, the survival capacity and evolution ceiling of complex systems are determined by the stability of internal complementary relationships; complementarity imbalance and synergy breakdown are the underlying common mechanisms of the decline of all complex systems.

3 Definition and Axiomatic Foundation of the Synergy Coefficient

3.1 Axiomatic Definition of the Product Form of the Synergy Coefficient

Let the five-dimensional state vectors of any two systems (or the same system at different moments) be:

$$\mathbf{x} = (x_1, x_2, x_3, x_4, x_5), \quad \mathbf{y} = (y_1, y_2, y_3, y_4, y_5), \quad x_i, y_i \in [0, 1]$$

Define the synergy mapping: $\kappa : [0, 1]^5 \times [0, 1]^5 \rightarrow [0, 1]$, satisfying the following axioms:

Axiom 1 (Zero-Synergy Axiom / Dimensional Independence). If there exists any dimension i satisfying $x_i = 0$ or $y_i = 0$, then $\kappa(\mathbf{x}, \mathbf{y}) = 0$.

Axiom 2 (Monotonicity Axiom). If $\forall i, x'_i \geq x_i, y'_i \geq y_i$, then $\kappa(\mathbf{x}', \mathbf{y}') \geq \kappa(\mathbf{x}, \mathbf{y})$.

Axiom 3 (Symmetry Axiom). The synergy relationship is bidirectionally equivalent: $\kappa(\mathbf{x}, \mathbf{y}) = \kappa(\mathbf{y}, \mathbf{x})$.

Combined with t-norm theory, it can be strictly proved[5] that the synergy function satisfying the above axioms must take the product form:

$$\kappa(\mathbf{x}, \mathbf{y}) = \prod_{i=1}^5 \gamma_i(x_i, y_i)$$

Unified dimensional matching degree standardization definition (where $a, b > 0$):

$$\gamma(a, b) = \min\left(\frac{a}{b}, \frac{b}{a}\right), \quad \gamma \in [0, 1]$$

Axiom 4 (Degeneration Axiom). When the synergy coefficient $\kappa = 0$ (i.e., there is no synergistic effect between systems), the five-dimensional synergy operation degenerates into the traditional addition operation. This indicates that traditional mathematics is the degenerate case of five-dimensional mathematics under the “no synergy” assumption.

3.2 Definitions of Self-Synergy and Inter-Synergy

Three basic types of synergy:

Temporal Self-Synergy: Refers to the synergy degree between the states of the same system at different times. Let the five-dimensional state of system \mathcal{S} at the benchmark moment t_0 be \mathbf{s}_0 , and the state at the current moment t be $\mathbf{s}(t)$. Then the temporal

self-synergy coefficient is defined as:

$$\kappa_{\text{self}}(t) = \prod_{d \in \{B, S, R, D, I\}} \gamma_d(s_d(t), s_{0d})$$

where γ_d is the dimensional matching function. Temporal self-synergy is used to monitor the degradation, aging, or sudden change of a system over time and is the core tool for system health diagnosis.

Intra-Dimensional Self-Synergy: Refers to the matching degree among the five dimensions within the same system, i.e., the internal cohesion health degree of the system. For an indivisible monolithic system (such as a building or a human body), its overall state can be evaluated through the product of the pairwise matching degrees of its internal dimensions:

$$\kappa_{\text{intra}} = \prod_{1 \leq d < e \leq 5} \gamma(s_d, s_e)$$

where $\gamma(s_d, s_e) = \min(s_d, s_e) / \max(s_d, s_e)$. Intra-dimensional self-synergy is a measure of the self-consistency of a monolithic system. When the various dimensions within the system mutually support each other without serious bottleneck weakness, the coefficient approaches 1.

Inter-Synergy: Refers to the synergy degree between two different systems (or different modules within the same system) at the same moment. Let the five-dimensional states of systems \mathcal{A} and \mathcal{B} be \mathbf{a} and \mathbf{b} respectively. Then the inter-synergy coefficient is defined as:

$$\kappa_{\text{inter}}(\mathcal{A}, \mathcal{B}) = \prod_{d \in \{B, S, R, D, I\}} \gamma_d(a_d, b_d)$$

Inter-synergy is used to evaluate the cooperation quality between two entities and is the basic tool for inter-subject collaboration analysis.

Functional Loss Operator: The functional loss of a system can be directly described by logical predicates without relying on numerical thresholds of the synergy coefficient.

Total Synergy Functional Loss: If there exists any dimension d in the five-dimensional state vector of system \mathcal{S} such that the matching degree $\gamma_d = 0$ (i.e., that dimension is completely mismatched), then the system undergoes total synergy functional loss, denoted as:

$$\mathcal{L}_{\text{total}}(\mathcal{S}) \equiv \bigvee_{d \in \{B, S, R, D, I\}} (\gamma_d = 0)$$

Partial Synergy Functional Loss: If system \mathcal{S} has a non-trivial decomposition $\mathcal{S} = \mathcal{S}_1 \oplus \mathcal{S}_2 \oplus \dots \oplus \mathcal{S}_k$ ($k \geq 2$), such that some subsystem \mathcal{S}_j undergoes total synergy functional loss (i.e., $\mathcal{L}_{\text{total}}(\mathcal{S}_j) = \text{true}$), then the system is said to undergo partial synergy

functional loss, denoted as:

$$\mathcal{L}_{\text{partial}}(\mathcal{S}) \equiv \exists \text{ non-trivial decomposition } \mathcal{S} = \bigoplus_i \mathcal{S}_i, \exists j, \mathcal{L}_{\text{total}}(\mathcal{S}_j) = \text{true}$$

This operator and the continuous synergy coefficient κ form complementary tools: κ measures the degree of synergy, while \mathcal{L} determines whether the function is completely lost. Together they constitute the dual-track system health assessment system of Five-Dimensional Systems Theory.

Relationships and Complementary Applications of the Three Types of Synergy:

- Self-synergy (temporal and intra-dimensional) focuses on the intrinsic health of a monolithic system, while inter-synergy focuses on the coupling between multiple subjects.
- For large indivisible systems (such as buildings or human bodies), the intra-dimensional self-synergy state of the system can be indirectly reflected by calculating the inter-synergy coefficients among sensor nodes of a distributed sensor network deployed internally.
- For tiny indivisible systems (such as atoms, molecules, or cells), the intra-dimensional self-synergy level can be inferred by observing the inter-synergy effects between the system and external systems.
- Self-synergy and inter-synergy can be used simultaneously and cross-referenced: taking a UAV formation as an example, treating the entire formation as a whole, calculating its temporal self-synergy coefficient can evaluate the synergistic evolution of the formation over time; if decomposed into individual UAVs, calculating the inter-synergy matrix among the UAVs can analyze the internal cooperation quality of the formation.
- Applications at the cosmic scale will be unfolded in Section 5.3.

3.3 The Intrinsic Relationship Between Entropy Increase and the Synergy Coefficient

Generally speaking, for the inter-synergy coefficient κ , the decay from 1 toward 0 corresponds to entropy increase, and vice versa corresponds to entropy decrease. Five-Dimensional Systems Theory unifies entropy increase/decrease within the dynamics of κ .

4 The Synergy Paradigm Classification of Five-Dimensional Systems Theory

Combining system decomposability and the Principle of Complementary Synergy, the synergistic relationships of complex systems are divided into four basic paradigms, forming a continuous evolutionary spectrum from monolithic to networked, from simple to complex.

4.1 Decomposability and Paradigm Classification

Define system **decomposability**: whether the overall core function of the system decays or is completely lost after being decomposed into several sub-units. The evolutionary progression relationship of the four synergy paradigms:

Independent Type \rightarrow Chopstick Type \rightarrow Master-Slave Type \rightarrow Scattered Type

Evolutionary logic: monolithic independent system \rightarrow binary equal coupling system \rightarrow core-subordinate hierarchical system \rightarrow decentralized multi-agent network system.

4.2 Independent Type (Monolithic)

The Independent Type is the basic elemental form of a system, belonging to an indivisible monolithic system. Its steady state relies on internal five-dimensional self-consistent matching and endogenous self-synergy. Typical objects: microscopic particles, organic life forms, monolithic buildings, independent UAV platforms. Quantitative tool: **self-synergy coefficient**, containing two analytical dimensions of temporal self-synergy and intra-dimensional self-synergy. Under this paradigm, complementary synergy is embodied as the dynamic equilibrium complementation of the five dimensions within the system. A single dimensional bottleneck weakness will lower the overall synergy level through coupling linkage.

4.3 Chopstick Type (Binary Equal Coupling)

The Chopstick Type synergy takes dual-subject equal dependence as its core characteristic. The two subjects have equal status, heterogeneous functions, and tight coupling binding. After separation, neither can achieve the original core function. Binary equal coupling is the classic form of high-intensity synergy. The two subjects are naturally complementary in multiple dimensions, generating composite functions that a single system cannot achieve. Typical objects: sexual reproduction systems, dual collaboration systems,

binary coupling structures. Quantitative tool: **inter-synergy coefficient**, characterizing the matching and coupling degree of the five-dimensional states of the two subjects.

4.4 Master-Slave Type (Centralized Hierarchical)

The Master-Slave Type synergy consists of a single core subject and multiple peripheral subordinate units. The core unit is indivisible and determines the core function of the system; the subordinate units can be independently separated, and after separation the system retains basic operating capabilities. After the binary equal structure undergoes differentiation in resources and capabilities, it gradually evolves into a core-dominated hierarchical architecture. The synergy intensity is determined by the complementary fit between the core and the subordinates: the core coordinates direction and order, while the subordinates are responsible for practical execution and scenario supplementation. Typical objects: cluster formations, hierarchical organizations, social governance systems, large-scale engineering control systems. Quantitative tool: **synergy matrix**, characterizing the pairwise inter-synergy levels between the core and each subordinate unit.

4.5 Scattered Type (Multi-Agent Equal Network)

The Scattered Type synergy is a completely decentralized, decomposable network system. Nodes have equal status and autonomous operation, relying on local spontaneous interaction to form global ordered evolution. After the hierarchical master-slave system undergoes decentralization evolution, control weight weakens, ultimately forming a distributed network structure. There is no strong constraint core. The overall emergence relies on the weak complementary superposition of massive nodes, possessing high resilience and high adaptability characteristics. Typical objects: open-source collaboration networks, industrial clusters, ecological communities, distributed intelligent manufacturing systems. Quantitative tool: **distributed synergy tensor**, adapted to multi-node high-order coupling correlation analysis.

4.6 Paradigm Comparison and Continuous Spectrum

Real complex systems are mostly composite systems with nested multi-paradigms. Within a single system, there can simultaneously exist hierarchical synergy, distributed synergy, and other multiple operating modes.

Table 2: Comparison of Synergy Paradigms in Five-Dimensional Systems Theory

Paradigm	Decomposability	Structural Feature	Typical Example	Analysis Tool
Independent Type	Completely indivisible	Monolithic autonomy	Building, life form, single equipment	Self-synergy coefficient
Chopstick Type	Indivisible (binary equal)	Heterogeneous coupling	Binary collaboration, dual system	Inter-synergy coefficient
Master-Slave Type	Core indivisible, subordinates decomposable	Hierarchical star	Cluster formation, hierarchical organization	Synergy matrix
Scattered Type	Completely decomposable	Distributed network	Industrial cluster, open-source network	Synergy tensor

4.7 The Independent Relationship Between System Decomposability and Synergy Degree

The synergy coefficient κ is determined solely by the five-dimensional matching relationship under the specified reference frame and has no direct binding with system decomposability: Decomposable systems can possess high synergy degrees, and indivisible monolithic systems can also have serious dimensional mismatch and low synergy. Decomposability judges the possibility of system reconstruction, while the synergy coefficient evaluates the health degree under the reference frame. Together they constitute the analysis toolbox of Five-Dimensional Systems Theory.

Combining the four synergy paradigms, the decomposition characteristics are summarized as follows:

- **Independent Type:** Completely indivisible; decomposition directly leads to the overall loss of the system;
- **Chopstick Type:** Binary strong coupling is indivisible; after separation, the core functions of both parties are completely lost;
- **Master-Slave Type:** The core is rigidly indivisible; subordinate units are decomposable; decomposition only changes the system boundary;
- **Scattered Type:** All nodes can be freely decomposed; decomposition retains monolithic function but loses global emergence.

4.8 Synergy Matrix and Higher-Order Tensors

For the Master-Slave Type (especially one-master-multi-slave type), the pairwise synergy between the subject and each subordinate can be uniformly characterized by the synergy matrix; for the Scattered Type (especially multi-node) system, the high-order coupling emergence effects among multiple nodes require the introduction of higher-order synergy tensors.

For an n -node complex hierarchical system, construct the $n \times n$ synergy matrix Γ , with element definitions:

$$\Gamma_{ij} = \kappa(\mathcal{S}_i, \mathcal{S}_j)$$

Uniformly quantifying the pairwise coupling synergy levels of multiple subjects, adapted to medium-scale complex systems such as master-slave formations and hierarchical organizations.

For distributed systems with ternary and higher-order coupling and strong emergence, introduce a third-order synergy tensor, defined using geometric mean standardization:

$$\mathcal{T}_{ijk} = \sqrt[3]{\kappa_{ij} \cdot \kappa_{ik} \cdot \kappa_{jk}}$$

This definition satisfies symmetry and degeneracy (if any pairwise synergy is 0 then the overall high-order synergy is zero), has simple calculation, and is adapted to engineering implementation applications.

5 The Application Spectrum of Five-Dimensional Systems Theory: From Engineering to Civilization

5.1 Engineering Layer: Four Typical Quantitative Cases

5.1.1 Independent Type Case: Self-Synergy Monitoring of Aging Building Reinforcement and Renovation

A six-story brick-concrete residential building from the 1980s is an indivisible monolithic system. Taking the initial construction period as the benchmark state $\mathbf{s}_0 = (B_0, S_0, R_0, D_0, I_0)$, the current state is $\mathbf{s} = (B, S, R, D, I)$. The normalized five-dimensional indicators are as follows:

- Boundary: $B_0 = 1.0$, $B = 0.85$ (foundation settlement and surrounding traffic vibration lead to increased equivalent load);
- Structure: $S_0 = 1.0$, $S = 0.70$ (wall cracks, mortar strength degradation);

- Reserve: $R_0 = 1.0$, $R = 0.20$ (design life 100 years, already used 80 years, remaining 20 years);
- Direction: $D_0 = 1.0$, $D = 0.95$ (foundation settlement causes slight deviation in force direction);
- Intensity: $I_0 = 1.0$, $I = 0.70$ (brick masonry compressive strength drops from 10MPa to 7MPa).

According to the definition in Section 3.2, the temporal self-synergy coefficient is the product of the five-dimensional matching degrees between the current state and the benchmark state, i.e.:

$$\kappa_{\text{self}} = \prod_{d \in \{B, S, R, D, I\}} \frac{\min(s_d, s_{0d})}{\max(s_d, s_{0d})} = 0.85 \times 0.70 \times 0.20 \times 0.95 \times 0.70 = \mathbf{0.079}$$

After reinforcement and renovation, the dimensions are updated: $B = 0.95$, $S = 0.95$, $R = 0.20$, $D = 0.95$, $I = 0.90$. The synergy after reinforcement:

$$\kappa'_{\text{self}} = 0.95 \times 0.95 \times 0.20 \times 0.95 \times 0.90 = \mathbf{0.154}$$

This quantitatively verifies the improvement effect of the reinforcement scheme on the system health degree.

The above five-dimensional indicators highly correspond to the core considerations of seismic fortification and reinforcement and renovation: Boundary B corresponds to site and foundation stability, Structure S corresponds to structural integrity, Reserve R corresponds to service life and safety reserve, Direction D corresponds to force direction consistency, and Intensity I corresponds to material seismic bearing capacity. This fitting relationship confirms the engineering rationality of Five-Dimensional Systems Theory.

5.1.2 Chopstick Type Case: Binary Coupling Synergy of Biological Reproduction

Female \mathcal{F} : $B_f = 0.9$, $S_f = 0.8$, $R_f = 0.7$, $D_f = 0.95$, $I_f = 0.6$ Male \mathcal{M} : $B_m = 0.8$, $S_m = 0.9$, $R_m = 0.6$, $D_m = 0.90$, $I_m = 0.8$

Dimensional matching degrees:

$$\gamma_B = \min\left(\frac{0.8}{0.9}, \frac{0.9}{0.8}\right) = 0.89, \quad \gamma_S = 0.89, \quad \gamma_R = 0.86, \quad \gamma_D = 0.95, \quad \gamma_I = 0.75$$

$$\kappa_{\text{inter}} = 0.89 \times 0.89 \times 0.86 \times 0.95 \times 0.75 = \mathbf{0.485}$$

After the female falls ill and her reserve drops to $R_f = 0.3$, $\gamma_R = 0.5$, and the synergy decays:

$$\kappa'_{\text{inter}} = 0.89 \times 0.89 \times 0.50 \times 0.95 \times 0.75 = \mathbf{0.282}$$

The synergy degree drops significantly, corresponding to a significant weakening of population reproduction capacity.

5.1.3 Master-Slave Type Case: Synergy Matrix Calculation of Aviation Formation

Table 3: Five-Dimensional Normalized States of Formation Units

Unit	B	S	R	D	I
Leader L	0.9	0.9	0.8	0.95	0.9
Wingman $W1$	0.8	0.7	0.6	0.90	0.7
Wingman $W2$	0.7	0.8	0.9	0.85	0.8
Wingman $W3$	0.6	0.6	0.5	0.80	0.6

Calculating the inter-synergy coefficients between the leader and each wingman according to the standardized matching degree:

$$\kappa_{L,W1} = 0.38, \quad \kappa_{L,W2} = 0.49, \quad \kappa_{L,W3} = 0.16$$

The synergy between Wingman W3 and the leader is significantly low, forming a synergy bottleneck weakness of the formation. Targeted task configuration adjustment is needed.

5.1.4 Scattered Type Case: Synergy Tensor of Distributed Intelligent Manufacturing

Initial five-dimensional states of nodes:

$$\text{AGV1: } (0.8, 0.7, 0.6, 0.9, 0.7), \quad \text{AGV2: } (0.7, 0.8, 0.5, 0.8, 0.8)$$

$$\text{R1 Robot Arm: } (0.6, 0.9, 0.8, 0.7, 0.9)$$

Initial pairwise synergy: $\kappa_{12} = 0.50, \kappa_{1R} = 0.27, \kappa_{2R} = 0.37$ High-order synergy tensor:

$$\mathcal{T}_{12R} = \sqrt[3]{0.50 \times 0.27 \times 0.37} \approx 0.37$$

After AGV1 battery drops to 0.4, the reserve dimension drops from 0.6 to 0.4, and the operating intensity is simultaneously limited (intensity dimension drops from 0.7 to 0.4). Recalculating:

$$\gamma_R(\text{AGV1}, \text{R1}) = \frac{0.4}{0.8} = 0.50, \quad \gamma_I = \frac{0.4}{0.9} \approx 0.44$$

$$\kappa'_{1R} = 0.75 \times 0.78 \times 0.50 \times 0.78 \times 0.44 \approx 0.10$$

κ_{12} becomes 0.28 due to intensity matching decline, and κ_{2R} remains 0.37. Then:

$$\mathcal{T}'_{12R} = \sqrt[3]{0.28 \times 0.10 \times 0.37} = \sqrt[3]{0.01036} \approx \mathbf{0.22}$$

This result precisely captures the global synergy decay triggered by local faults in a distributed system.

5.2 Global Governance Layer: A Community with a Shared Future for Mankind

The core logic of a community with a shared future for mankind can be fully interpreted through Five-Dimensional Systems Theory: global governance contradictions are not the absolute strength gap among countries but the multi-dimensional synergy imbalance of boundary rules, governance structure, resource reserves, development direction, and responsibility sharing. The “common but differentiated responsibilities” of the Paris Agreement is a typical practice of the Principle of Relativity in global governance: abandoning absolute index control, and differentiating division of labor based on relative differences in development stage, historical responsibility, and governance capability. The sustainable development of human civilization is essentially the continuous optimization of the five-dimensional synergy level of the global mega-system. The construction of a community with a shared future for mankind is essentially the dynamic tuning process of the global governance reference frame from pluralistic fragmentation toward synergistic integration.

5.3 Cosmic Civilization Layer: Five-Dimensional Energy Synergy of Interstellar Civilizations

The traditional Kardashev index classifies civilization levels by absolute energy consumption, which has obvious absolutization limitations. Five-Dimensional Systems Theory points out that the core of civilization survival is multi-dimensional dynamic equilibrium rather than unlimited expansion of energy intensity. The collapse risk of high-order interstellar civilizations generally stems from dimensional mismatches such as boundary overload, structural imbalance, resource misallocation, and direction deviation; super-projects such as Dyson spheres and cross-galaxy resource scheduling are essentially five-dimensional tuning means for super-large-scale systems, relying on complementary synergy to maintain the long-term steady state of interstellar civilizations. Viewing the universe itself as a super-large indivisible system, its internal five-dimensional state cannot be directly decomposed and observed, but the evolutionary trend of the universe

can be indirectly inferred through the inter-synergy coefficients among galaxies, between dark matter and visible matter, and between gravitational waves and matter distribution. This together with the five-dimensional tuning of interstellar civilizations constitutes the complete application of Five-Dimensional Systems Theory at the cosmic scale.

6 Dialogue Between Five-Dimensional Systems Theory and Classical System Paradigms

Dialogue with General Systems Theory: Bertalanffy laid the foundation of system concepts[1]. Five-Dimensional Systems Theory concretizes vague element interaction relationships into five standardized dimensions, adding quantitative tools such as synergy coefficients, realizing the leap of system theory from qualitative description to quantitative calculation.

Dialogue with Cybernetics: Wiener constructed control theory with feedback as the core[2]. Five-Dimensional Systems Theory further reveals the essence of feedback: relying on dynamic monitoring of synergy degree deviations, correcting system inputs and operating intensity, and achieving closed-loop control of multi-dimensional matching.

Dialogue with Self-Organization Theory: Prigogine’s dissipative structure theory explains the evolutionary conditions from disorder to order[6]. Combined with the Process Reference Frame Principle, Five-Dimensional Systems Theory fits the core idea of system generative theory, providing standardized descriptive language and quantitative tracking means for the generative evolution process[7].

Dialogue with Complexity Science: Holland takes emergence as the core characteristic of complex systems[3]. Five-Dimensional Systems Theory defines the critical conditions for emergence: heterogeneous complementarity reaches the threshold, and multi-dimensional synergy breaks through the phase transition critical point, providing quantifiable judgment criteria for emergence phenomena.

7 Conclusion and Outlook

Five-Dimensional Systems Theory, standing at the cross-disciplinary perspective of systems science and systems philosophy, constructs a unified theoretical framework with five dimensions—Boundary, Structure, Reserve, Direction, and Intensity—as the core. Relying on the Principle of Relativity and the Principle of Complementary Synergy to solidify its philosophical foundation, it achieves full-scenario quantitative analysis through synergy coefficients, synergy matrices, and higher-order synergy tensors.

Contributions to the Philosophy of Systems Science: 1) Resolving the inherent tension between holism and reductionism, using five-dimensional decomposition to retain the quantitative advantages of reduction analysis, and using synergistic coupling to interpret holistic emergence characteristics; 2) Perfecting the theoretical system of system generative theory, combining the Process Reference Frame Principle, using multi-dimensional relational dynamic evolution to explain the complete process of system generation, iteration, and decay; 3) Bridging the implementation gap between theory and application, constructing a complete chain of “worldview—axiomatic system—quantitative tool—engineering application”; 4) Sublimating the philosophy of relativity and complementarity, establishing the core position of “relative relationships take priority over absolute attributes” in systems philosophy.

The four synergy paradigms completely cover all system forms from monolithic, binary coupling, hierarchical organization to distributed network, clarifying the evolutionary laws and structural logic of complex systems. Multi-scale engineering cases, social governance systems, and interstellar civilization deduction jointly verify: a single absolute index cannot determine the fate of a system. Multi-dimensional dynamic matching, heterogeneous complementary synergy, and multi-element equilibrium are the core essence of the steady-state survival and long-term evolution of complex systems.

Future Outlook: The further development of Five-Dimensional Systems Theory will unfold in the following directions:

1. **Five-Dimensional Calculus:** When the system state evolves continuously with time, the rate of change of the synergy coefficient $\frac{d\kappa}{dt}$ can be defined as the synergy flow, establishing the differential equation of synergy dynamics. For example, $\frac{d\kappa}{dt} = \kappa \sum_d \frac{\dot{\gamma}_d}{\gamma_d}$, providing a continuous mathematical model for system degradation prediction and health management.
2. **Five-Dimensional Signal Processing:** Treating the five-dimensional state vector as a multi-dimensional signal, introducing tools such as synergy filters and synergy spectrum analysis. For example, in distributed sensor networks, by calculating the inter-synergy coefficient matrix among sensor nodes, a synergy Kalman filter can be designed to achieve efficient fusion of multi-source information and fault detection.
3. **Higher-Order Synergy Tensors and Discrete Combinatorial Emergence:** The third-order synergy tensor defined in this paper can be naturally generalized to fourth-order, fifth-order, and even arbitrary higher orders, used to characterize the collective emergence effects of multiple subjects (n nodes) in finite-dimensional discrete systems. Combined with dimensionality reduction techniques such as ten-

sor decomposition and graph neural networks, computational complexity can be reduced, and it can be applied to medium-scale complex systems such as brain networks, social networks, and intelligent agent clusters.

4. **Five-Dimensional Functional Analysis:** When the system state is distributed in continuous space (such as a field) or infinite-dimensional function space, the synergy coefficient is generalized to a synergy functional. The spectral theory of synergy operators can be established to study characteristic synergy modes and their stability, providing a rigorous mathematical foundation for the synergistic evolution of complex systems such as turbulence, climate, and brain networks.

Five-Dimensional Systems Theory can provide a new research path for paradigm innovation in systems science, quantitative evaluation of complex systems, and theoretical expansion of systems philosophy, providing original theoretical support for the analysis and governance of complex problems in multiple fields such as nature, engineering, society, and civilization.

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