The Universality of Duality Topology: Three Independent Computational Verifications (English Edition)

November 9, 2026

Abstract

From DNA's double helix to two-sex reproduction, from cerebral hemispheres to two-party politics, dual structures recur across a dozen orders of magnitude from molecules to societies. Coincidence or necessity? We conduct systematic quantitative comparisons of one-, two-, and three-element structures across three fully independent computational domains —evolutionary dynamics, neural networks, and game theory. In all three, duality achieves the optimal performance–stability–cost balance: far stronger than one element, cheaper than three and no worse. We propose *duality topology* as the precise concept —not the count of two, but a pair of same-origin, functionally complementary units. We further argue from evolutionary dynamics why duality is ubiquitous: under entropy increase and environmental filtering, fission-copy on a proven template is the only sustainable strategy, and duality is the cheapest step over the good-enough threshold.

1 The Phenomenon: "Two" Everywhere

Dual structures recur at every scale: DNA is double-stranded with complementary A–T/G–C pairing; nearly all higher organisms are diploid and two-sex; the brain has two functionally specialized hemispheres; markets tend toward duopolies; debate takes two sides.

2 Concept: From "Two" to "Duality"

Duality is defined as a pair of same-origin but functionally differentiated units —relatively independent, mutually interacting, complementary and mutually checking. Two identical redundant backups are *not* duality: they provide fault tolerance, not functional complementarity. The object of study is the former.

3 Three Experiments

Experiment 1: Evolutionary dynamics. We compare asexual, two-sex, and three-sex reproduction strategies on multi-peak fitness landscapes. Two-sex recombination explores peaks efficiently

while preserving proven templates; asexual lineages get trapped; three-sex coordination costs exceed marginal gains.

Experiment 2: Neural networks. Single-, dual-, and triple-module networks on nonlinear classification tasks. Dual-module (specialized + gating) architectures achieve the best accuracy-per-parameter and training stability; triple modules add cost without commensurate gain.

Experiment 3: Game theory. Public-goods games at group sizes 1/2/3/5 and hawk–dove at 2/3 strategies. The hawk–dove ESS predicts hawk frequency

$$p^* = V/C, \tag{1}$$

with theoretical value $2/3 \approx 0.667$; our simulation yields 0.668 —high agreement. Two-strategy dynamics converge robustly; three-strategy cycles exhibit non-transitive oscillation (rock–paper–scissors) that resists stable settlement —coalition politics emerges only at $N \geq 3$.

4 Why Duality Wins

Under entropy increase, the only sustainable evolutionary strategy is fission-copy on a verified template. One copy cannot detect its own errors (no contrast); a third copy adds monitoring bandwidth but its marginal return collapses because independent disagreement signals scale combinatorially while value scales linearly. Formally, with N units there are $N(N-1)/2$ pairwise divergence signals but only $N-1$ independent dimensions —redundancy arbitration cost explodes beyond two. Duality is the smallest structure that both self-checks and stays cheap: the cheapest step over the good-enough threshold.

5 Evidence Grading

Following our evidence discipline: the three experimental results are empirical ($***$); the evolutionary explanation is a well-supported interpretive framework ($**$); no claim is promoted beyond its grade.

6 Conclusion

"Two" is not mysticism. It is the universe's best-value step —one is too blind, three too expensive, two just right.