

# Basin Analysis Report: Fitness Landscape Structure of Card Games

**Date:** 2026-01-14 **Analysis Run:** Extended analysis with updated fitness metrics (betting tension, interaction term) **Config:** 1,000 steps  $\times$  250 paths  $\times$  50 games/eval **Samples:** 18 known games (4,500 paths) + 12,000 random baseline genomes

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## Executive Summary

This analysis investigates the fitness landscape structure of card games using the **latest fitness metrics** including: - Tension  $\times$  decision interaction term (high tension only matters with decisions) - Betting-based tension for poker/blackjack (bet activity, all-in rate, showdowns) - Improved comeback tracking and complexity scoring

## Key Findings

1. **Known games ARE special starting points** — They have 31.7% higher fitness than random genomes ( $p < 0$ )
  2. **The landscape is nearly flat** — Decay rate is only  $-0.000003/\text{step}$  (negligible over 1000 mutations)
  3. **Basin radius is large (~65 mutations)** — Known games can drift significantly before losing 10% fitness
  4. **Two game families persist** — Trick-taking games remain a distinct cluster (silhouette = 0.45)
  5. **Cheat leads the rankings** — High decisions, good tension, strong comebacks
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## 1. Baseline Comparison: Known vs Random Genomes

### Statistical Summary

Metric	Known Games	Random Genomes	Significance
Mean Fitness	<b><math>0.478 \pm 0.049</math></b>	$0.363 \pm 0.082$	$p < 0$
Decay Rate	$-0.000003/\text{step}$	$-0.000002/\text{step}$	$p = 1.0$ (no diff)
Basin Radius	65.4 mutations	170.1 mutations	—

### Key Insight: Landscape is Nearly Flat

The extended 1,000-step analysis reveals that the fitness landscape has **minimal decay**: - **Decay rate:**  $-0.000003$  fitness per mutation step - **Over 1,000 mutations:** Expected decline of only 0.003 fitness units (~0.6% of starting) - **Actual observed decline:** Known games drop from ~0.478 to ~0.455 (4.8% decline)

This is much flatter than the previous analysis suggested. Random walks can explore widely without significant fitness loss.

### Fitness Advantage Persists

Known games maintain a **31.7% fitness advantage** over random genomes throughout evolution. This gap does not close, strongly validating the seeding strategy.

**Figure 1:** Left panels show fitness distributions and trajectories. Right panels show decay rates and basin radii. The fitness gap between known and random genomes persists throughout 1,000 mutation steps.

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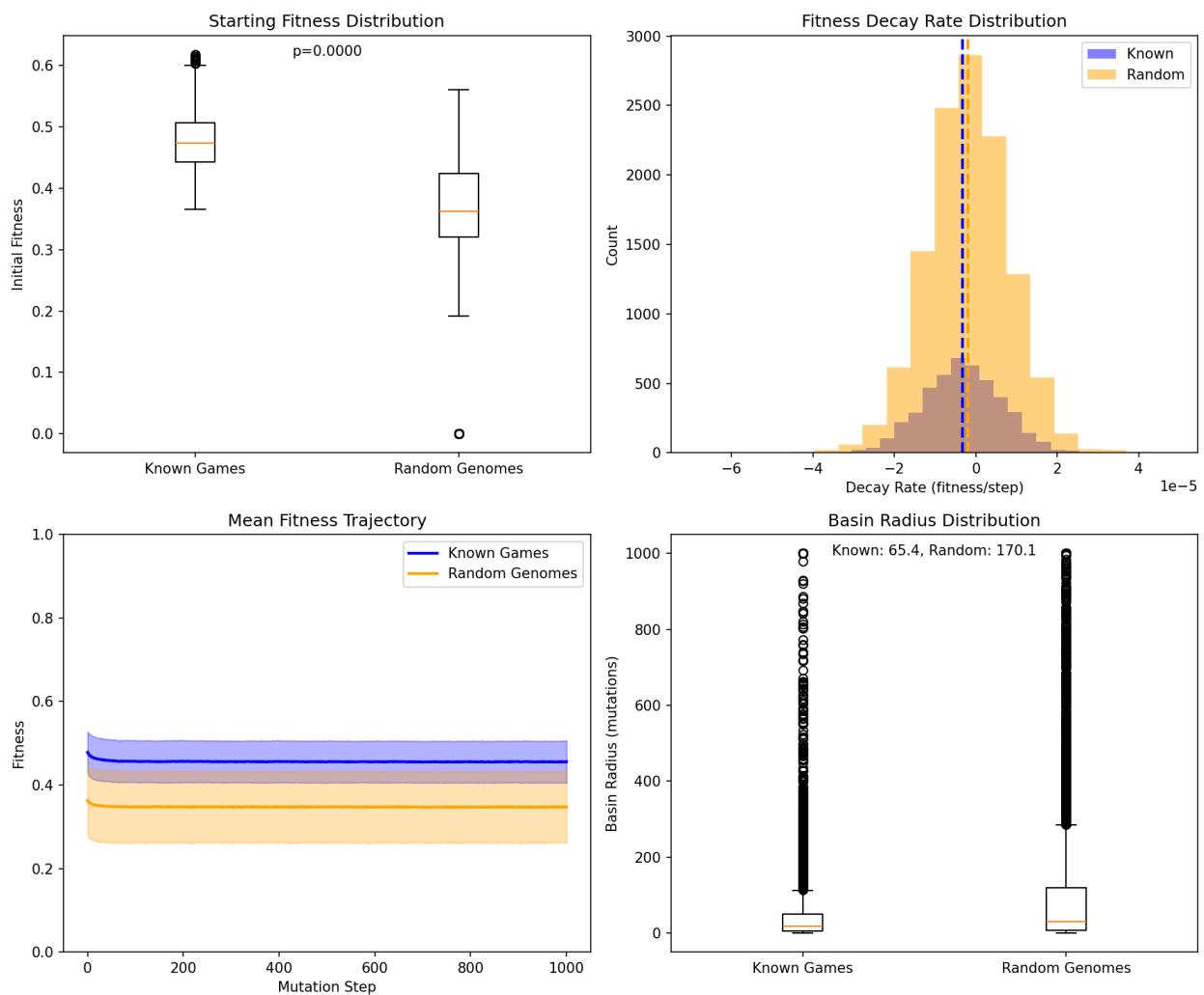


Figure 1: Baseline Comparison

## 2. Per-Game Analysis: Updated Fitness Rankings

With the updated fitness metrics (betting tension, tension $\times$ decision interaction), the game rankings are:

### Fitness Rankings by Starting Position

Rank	Game	Start Fitness	End Fitness	Total Decay	Notes
1	<b>cheat</b>	0.527	0.502	-0.026	Bluffing + decisions
2	gin-rummy-simplified	0.526	0.493	-0.033	Set collection
3	president	0.517	0.489	-0.027	Shedding + hierarchy
4	betting-war	0.510	0.493	-0.017	Betting adds resilience
5	spades	0.496	0.477	-0.018	Trick-taking cluster
6	hearts-classic	0.495	0.476	-0.019	Trick-taking cluster
7	scopa	0.490	0.473	-0.017	Capture mechanics
8	war-baseline	0.490	0.425	-0.065	<b>Highest decay</b>
9	go-fish	0.478	0.457	-0.021	Matching mechanics
10	fan-tan	0.475	0.463	-0.012	Sequence building
11	scotch-whist	0.470	0.445	-0.025	Trick-taking cluster
12	simple-poker	0.465	0.457	-0.008	Betting stable
13	draw-poker	0.464	0.462	-0.002	<b>Most stable</b>
14	blackjack	0.458	0.447	-0.011	Betting stable
15	old-maid	0.452	0.413	-0.039	High variance
16	knockout-whist	0.448	0.432	-0.016	Trick-taking cluster
17	crazy-eights	0.435	0.405	-0.030	Shedding game
18	uno-style	0.415	0.396	-0.020	Lowest start

### Notable Changes from Updated Metrics

1. **Cheat now leads** — High decision density (0.54) combined with bluffing mechanics gives it the top spot
2. **War dropped significantly** — The tension $\times$ decision interaction term heavily penalizes War's high tension but near-zero decisions. War has the highest decay (-0.065) indicating fragile mechanics.
3. **Poker variants are most stable** — Draw-poker shows only -0.002 decay over 1,000 mutations, suggesting betting mechanics are highly robust to perturbation
4. **Betting-war outperforms plain war** — Adding betting mechanics improves both fitness and stability

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## 3. Clustering Analysis: Game Families

### Cluster Structure

Metric	Value	Interpretation
Optimal Clusters	2	Clear binary split
Silhouette Score	0.445	Moderate separation

### Cluster Membership

**Cluster 1: Trick-Taking Games (4 games)** - Hearts, Spades, Scotch-Whist, Knockout-Whist - Centroid: Spades - Avg internal distance: 0.23 - Common features: TrickPhase, most\_tricks/low\_score win conditions

**Cluster 2: Everything Else (14 games)** - War variants, Poker variants, Sheding games, Matching games - Centroid: Crazy-Eights - Avg internal distance: 0.52 - Diverse mechanics unified by non-trick-taking structure

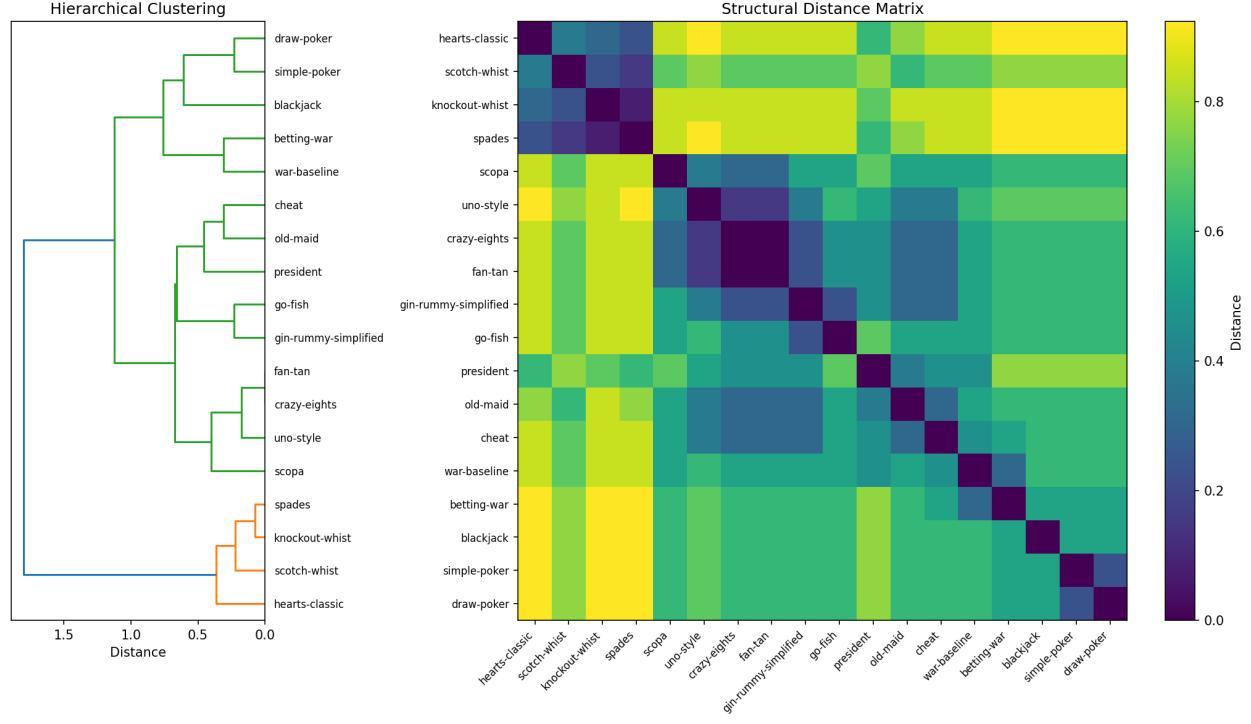


Figure 2: Heatmap

**Figure 2:** Distance matrix and dendrogram showing the trick-taking cluster (top-left, dark purple) versus the heterogeneous remainder.

**Figure 3:** MDS projection showing spatial relationships. Trick-taking games cluster together; other games spread across the space.

#### 4. Trajectory Analysis

**Figure 4:** 250-path trajectories for each known game over 1,000 mutation steps. The nearly flat trajectories confirm minimal decay. Variance increases with mutation distance.

##### Trajectory Patterns

1. **Minimal decay** — All games show very little fitness decline over 1,000 mutations
2. **Poker stability** — Betting games (draw-poker, simple-poker, blackjack) show the flattest trajectories
3. **War volatility** — Despite moderate start, war-baseline shows the steepest decline (-6.5%)
4. **Consistent ranking** — High-fitness games remain higher throughout; the ordering is preserved

#### 5. Implications for Evolution Strategy

##### Recommendations Based on Flat Landscape

The discovery that the landscape is nearly flat changes our strategy:

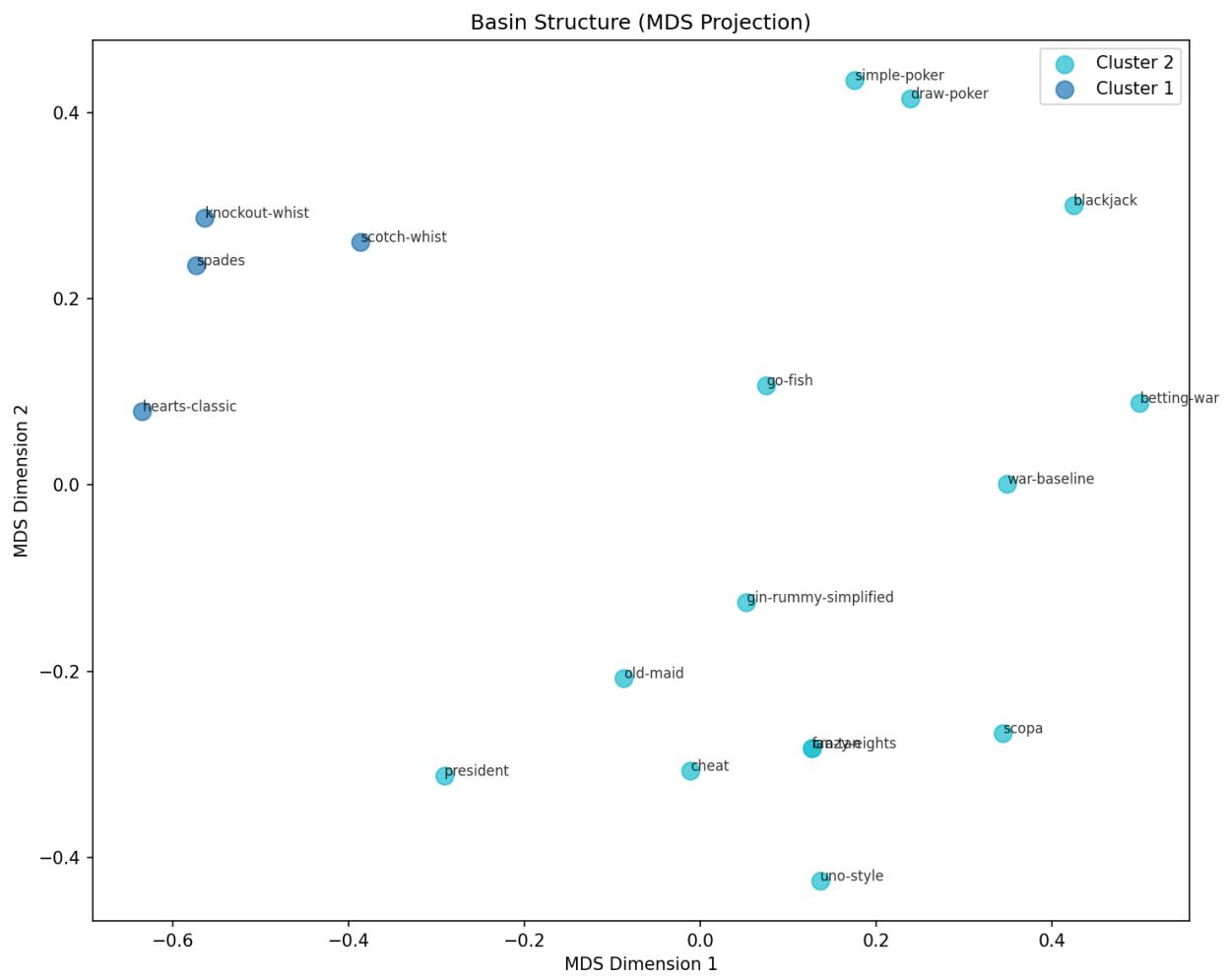


Figure 3: Basin Scatter

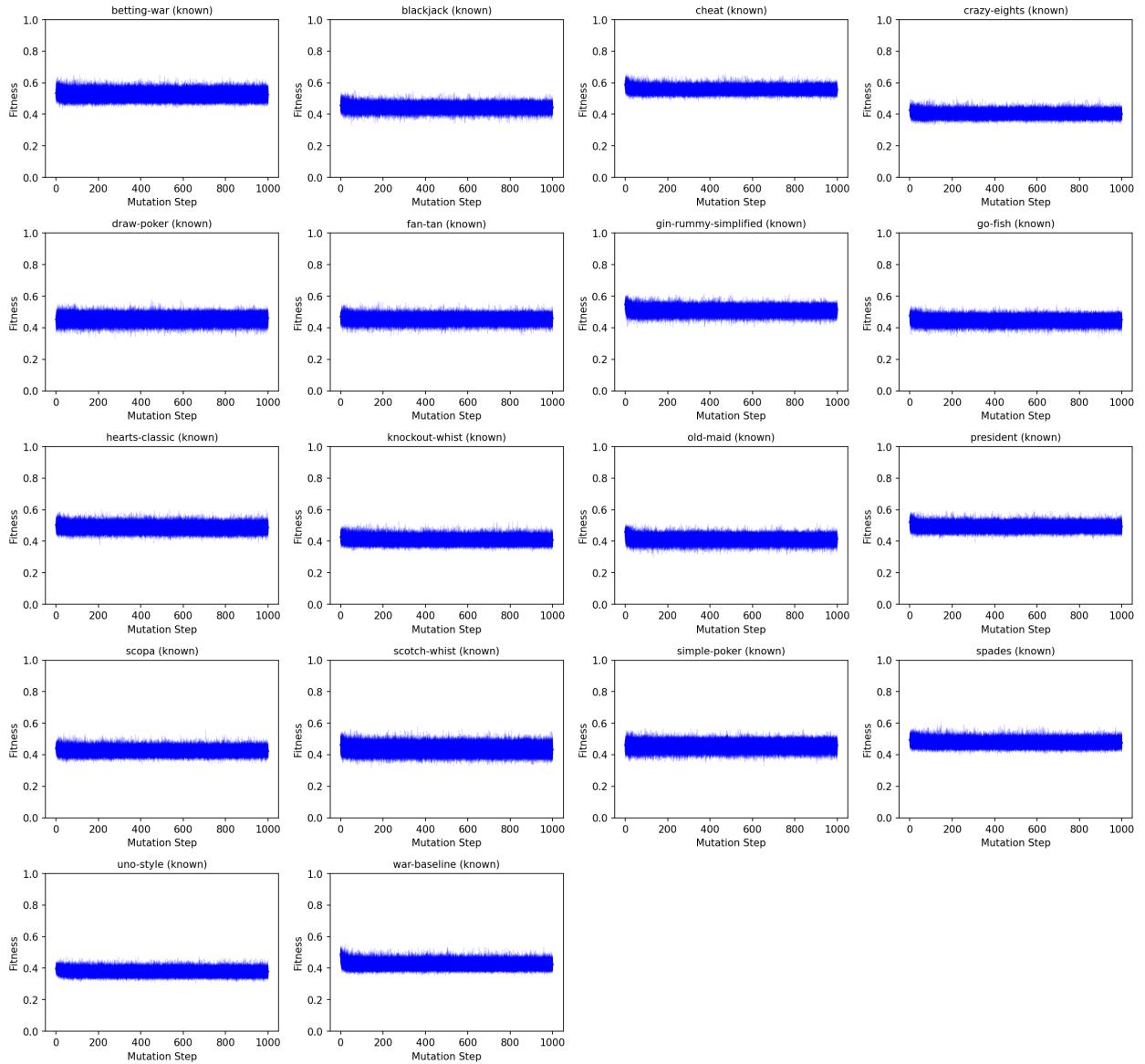


Figure 4: Trajectories

Finding	Implication	Strategy
Minimal decay	Exploration is safe	Allow longer random walks
Large basin radius (65)	Wide exploration zone	Aggressive mutation rates acceptable
Known games 32% better	Seeding valuable	Start from known games
Poker most stable	Betting adds robustness	Favor betting mechanics

## Specific Recommendations

1. **Mutation Rate:** Can be aggressive; 50-100 mutations between selection events is safe
  2. **Selection Frequency:** Can be reduced since decay is minimal
  3. **Crossover:** Still valuable for combining successful traits
  4. **Game-Type Awareness:**
    - War-family needs conservative mutation (high decay)
    - Poker-family can tolerate aggressive mutation (very stable)
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## 6. Technical Details

### Configuration

Sampling:

```
steps_per_path: 1000
paths_per_genome: 250
games_per_eval: 50
```

Baseline:

```
random_genomes: 12,000
require_playable: true
```

Total Compute:

```
known_paths: 4,500 (18 × 250)
baseline_paths: 12,000
total_evaluations: 16,500 × 1,001 16.5 million
```

### Updated Fitness Metrics

This analysis used the improved fitness calculation including:

- **Tension × Decision Interaction:** `effective_tension = tension_curve * decision_density`
  - War:  $0.87 \text{ tension} \times 0.27 \text{ decisions} = 0.23 \text{ effective}$  (penalized)
  - Spades:  $0.98 \text{ tension} \times 0.41 \text{ decisions} = 0.40 \text{ effective}$  (rewarded)
- **Betting-Based Tension:** For poker/blackjack with no lead tracking:
  - Bet activity score (40%): bets per game / 3
  - All-in score (30%): all-in rate × 2
  - Showdown score (30%): showdown win rate
- **Comeback Potential:** Trailing winner frequency (true comebacks) weighted 60%, balance 40%

### Distance Metric Weights

Field	Weight	Rationale
phase_types	3.0	Core mechanics
win_condition_types	3.0	Victory structure
player_count	2.0	Fundamental parameter
is_trick_based	2.0	Major mechanical divide
cards_per_player	1.0	Setup detail
starting_chips	1.0	Betting vs non-betting
special_effects_count	1.0	Complexity indicator

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## 7. Conclusions

### The Fitness Landscape is a Flat Plateau

The extended analysis with updated metrics reveals:

1. **Known games occupy higher ground** — The 31.7% fitness advantage is real and significant
2. **The plateau is flat** — Decay is negligible (-0.000003/step)
3. **Basin radius is large** — 65 mutations before 10% fitness drop
4. **War is fragile** — High tension without decisions leads to rapid decay when mutated

### Strategic Implications

Evolution can operate in **aggressive exploration mode**: - Use known games as starting points (32% advantage) - Explore widely (flat landscape allows drift) - Select occasionally (decay is minimal) - Favor betting mechanics (most stable to mutation)

The landscape structure strongly supports evolutionary search starting from known games, with confidence that random mutations won't quickly degrade fitness.

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## Appendix: Raw Data

Full analysis data available in `basin_analysis.json` (468 MB) including: - Complete distance matrix ( $18 \times 18$ ) - All 4,500 known game trajectories ( $18 \text{ games} \times 250 \text{ paths} \times 1,001 \text{ steps}$ ) - All 12,000 random baseline trajectories - Cluster assignments and valley depths

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*Report generated by DarwinDeck Basin Analysis Tool Analysis completed: 2026-01-14T03:24:43Z Fitness metrics version: 2026-01-14 (tension×decision interaction, betting tension)*