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Friction Bloom - Dataset 001

Technical Evaluation of Agent Adaptability: Grid Scaling and Friction-Induced Pathfinding Novelty

1. Introduction and Methodological Framework

In the evaluation of autonomous kinematic systems, strategic robustness is measured by an agent's capacity to maintain utility recovery when subjected to unforeseen spatial perturbations. This report dissects the adaptability of pathfinding agents traversing varied grid dimensions while facing "friction" disruptions—controlled morphological characteristics designed to challenge baseline navigational logic. By quantifying the transition from nominal pathing to emergent structures, we define the operational limits of autonomous adaptability within constrained simulations.

To evaluate these interactions, we utilize a multi-parameter metric framework:

- **Bloom Score:** A composite quantitative index representing the structural integrity and quality of emergent pathing. This metric establishes a functional "floor" of 2.0 for all **Stable** outcomes (as evidenced in Runs 12, 24, 32, and 40) and scales toward 4.0 in high-performance adaptations.

- **Novelty:** A comparative measure of spatial divergence between the baseline trajectory and the perturbed path. Scores ranging from 0.35 to 0.65 typically signify a transition from local noise to global route reconfiguration.
- **Coherence:** A metric of algorithmic consistency. A standard value of 2.0 across the dataset indicates that even under high friction, the agent's movement remains logically grounded rather than stochastic.
- **Chaos:** A measure of non-functional or erratic kinematic behavior. In successful "Bloom" states, this value is maintained at 0.0, indicating purposeful adaptation.

Experimental Scope

The simulation environment utilizes grid scaling from **5x5** to **15x15**. Agents were subjected to four specific friction perturbations: `block_first_third`, `block_baseline_midpoint`, `add_scattered_obstacles`, and `add_wall_gap_constraint`. This report analyzes how these variables interact to produce stable, noisy, or "blooming" agent behaviors.

2. Scaling Analysis: Grid Dimensions vs. Agent Performance

Grid scaling represents a fundamental stress test for pathfinding algorithms, as increased spatial volume alters the density and relevance of environmental obstructions. As the search space expands, the agent's ability to maintain a high-novelty recovery route is often inversely proportional to the sparsity of the perturbation.

Scaling Data Synthesis

The following data correlates environmental scale with mechanical step-counts, path novelty, and final behavioral outcomes:

Run ID	Grid Size	Steps	Novelty	Friction Type	Outcome
Run 1	5	8	0.36	block-first-third	Bloom
Run 37	15	28	0.34	block-first-third	Noise
Run 4	5	8	0.50	scattered-obstacles	Bloom

Run ID	Grid Size	Steps	Novelty	Friction Type	Outcome
Run 40	15	28	0.00	scattered-obstacles	Stable

Critical Evaluation of Spatial Scaling

The data reveals a significant degradation in friction efficacy for `add_scattered_obstacles`as the grid dimensions increase. While this friction drives high novelty (0.50) at a 5x5 scale (Run 4), it results in a **Stable** outcome with 0.0 Novelty at 10x10, 12x12, and 15x15 scales (Runs 24, 32, 40). The technical explanation lies in the geometric sparsity: the obstacle density decreases relative to the square of the grid dimension. Consequently, the probability of a stochastic obstacle intercepting the baseline right-angle path decreases, allowing the agent to maintain its primary logic without adaptation.

3. Categorical Assessment of Friction Modalities

Friction types serve as controlled disruptions that force the agent into emergent behaviors. Our analysis categorizes these based on their capacity to elicit macro-scale route reconfigurations.

High-Impact Frictions: Topological Bottlenecks

The `add_wall_gap_constraint` and `add_scattered_obstacles` (at lower scales) are identified as primary drivers of novelty.

- **`add_wall_gap_constraint`:** This modality functions as a high-value **topological bottleneck**. Unlike scattered obstacles, it forces a macro-level deviation. In Run 31 (Size 12, Novelty 0.65) and Run 27 (Size 11, Novelty 0.65), the agent is forced to abandon its horizontal traverse early to intercept specific coordinates, resulting in near-maximum Bloom Scores (~3.94).

Low-Impact Frictions: Local vs. Global Optimization

The `block_baseline_midpoint` friction consistently failed to provoke high-value adaptation.

- **Analysis of Failure:** In Run 38 (Size 15), the agent achieved a Novelty score of only 0.07, remaining **Stable**. Because the disruption is localized at the midpoint of a long traverse, the agent performs a minor "local optimization"—a small deviation—rather than a "global" route reconfiguration. These "Noise" outcomes (e.g., Run 14, Size 8) indicate that the perturbation is too narrow to disrupt the agent's overall utility profile meaningfully.

4. Robustness and Pathfinding Novelty Evaluation

Robustness is defined by the agent's ability to maintain destination-reaching utility while adopting highly novel path structures.

Synthesis of Pathing Kinematics

The standard "Baseline Path" follows a rigid L-shape: a horizontal traverse along the y=0.5 axis followed by a vertical descent at the far right of the grid. High-novelty "Bloom" runs demonstrate a distinct "stair-step" or "early-descent" strategy.

For instance, in **Run 19 (Size 9)**, the agent executes a "mid-path drop" at x=3.5, whereas the baseline would have continued to x=8.5. Similarly, in **Run 27 (Size 11)**, the agent drops vertically at x=4.5 rather than the baseline x=10.5. These spatial deviations represent a fundamental shift in the agent's navigation logic to solve for the wall-gap bottleneck.

Outcome Distribution and Thresholds

The dataset correlates specific "Notes" with novelty thresholds:

- **Bloom (Novelty > 0.35):** "Agent recovered through a novel viable route." Represents successful utility recovery through structural adaptation.
- **Noise (Novelty 0.10–0.33):** "Behavior changed, but adaptation was weak or inefficient." Associated with localized corrections (e.g., Run 14, Run 33).
- **Stable (Novelty < 0.10):** "Friction did not meaningfully alter behavior." Common in larger grids where obstacles are easily bypassed (e.g., Run 32, Run 40).

5. Conclusion: Synthesized Findings on Agent Adaptability

This investigation concludes that autonomous adaptability is a function of the geometric relationship between the scale of the search space and the structural nature of the perturbation.

Strategic Synthesis:

1. **Stressor Efficacy:** For the purposes of testing or training autonomous systems, grid scaling and friction types cannot be treated as independent variables. The `add_wall_gap_constraint` acts as a **scale-invariant stressor**, maintaining consistent Novelty scores (~0.6+) across all tested dimensions.
2. **Threshold Limits:** The `add_scattered_obstacles` friction is **scale-dependent**. It is highly effective in small-scale environments but loses all utility in environments larger than 10x10 due to increased spatial sparsity.
3. **Kinematic Recommendation:** To elicit maximum adaptability and complex emergent structures, designers should utilize **structural bottlenecks** (Wall Gaps) over **stochastic perturbations** (Scattered Obstacles). Bottlenecks force a global route reconfiguration that provides a far more rigorous test of an agent's pathfinding resilience.