Technical Explanation

1. Problem

The original frontier-selection logic, based mainly on heading projection and distance ranking, often caused oscillation and stagnation in random maze environments.

2. Design Concept

The new method follows the principle of information-driven yet goal-oriented navigation. The frontier decision is reformulated as a multi-factor weighted-score problem:

- Maintain smooth local motion by favoring frontiers aligned with the current heading.
- Guide long-term progress by weighting proximity to the ultimate goal.
- Encourage exploration by estimating local information gain from surrounding unknown cells.
- Ensure robustness through automatic switching to the goal path when close to the target.

The original framework and function interface remain unchanged.

3. DImplementation Method

- **Frontier Detection and Fallback Mechanism**

The system first checks the frontier array. If the robot is within 2.5 × arrival tolerance of the goal, the system directly plans a path to the final goal to prevent idle wandering.

- **Feature Functions**

`heading_alignment()` – cosine similarity between robot heading and vector to frontier, promoting forward continuity.
`goal_progress()` – negative Euclidean distance from frontier to goal, encouraging global convergence.
`proximity()` – negative BFS distance, favoring reachable, nearby frontiers.
`unknown_ratio()` – proportion of unknown cells in a 3×3 neighborhood, approximating information gain.

- **Composite Scoring Function**

A weighted sum balances exploration and goal seeking:
`Score=2.0×Alignment+1.0×Proximity+1.5×Progress+2.0×UnknownRatio.`
Higher emphasis (2.0) on alignment and unknown ratio promotes stable forward motion and active exploration, while moderate weighting on goal progress (1.5) maintains global direction, and lower weight on proximity (1.0) prevents over-favoring nearby. The frontier with the highest score becomes the next exploration target; if its distance to the goal is below 1.5× tolerance, it is snapped to the goal for efficiency.

4. Results and Conclusion

Tests with seeds 6, 243, and 463 showed smooth exploration and successful goal arrival with no oscillation. The weighted frontier-selection method achieves balanced exploration and goal-driven navigation, enhancing stability and efficiency without altering the system framework.