Path Planning in Dynamic Environments

A hierarchical global+local planning framework on gridworlds

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Outline

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Why Dynamic Environments Are Hard

- **Time-varying feasibility:** free space changes over time.
- **Partial observability:** agent only sees a local neighborhood.
- **Real-time constraint:** replanning from scratch can be too slow.
- **Safety:** must avoid both static and moving obstacles online.

Idea: combine long-horizon structure (global) with short-horizon reaction (local).

Scope & Contributions

Setting: single holonomic agent on a 2D discrete grid with static + moving obstacles.

Contributions

- Hierarchical planner: **global waypoint path** + **local reactive navigation**.
- Unified evaluation across global planners (BFS/DFS/Dijkstra/A*) and local planners.
- Path post-processing: **line-of-sight sparsification** + **safety-margin enforcement**.

Outline

Gridworld Model

- State: $S = \{(x, y)\}$ with discrete space/time.
- Actions: $A = \{(0, 1), (0, -1), (-1, 0), (1, 0), (0, 0)\}$.
- Static obstacles: $O \subset S$.
- Moving obstacles vary over time: M_i at time step i.
- Observation: local 5×5 occupancy grid centered on the agent.

Planning Objective

Find a trajectory $T = \{S_0, S_1, \ldots, S_{N-1}\}$ such that:

- S_0 is start and S_{N-1} reaches the goal.
- For each step, $\exists a \in A$ with $f(S_i, a) = S_{i+1}$.
- Safety constraints: $S_i \notin O$ and $S_i \notin M_i$.

Challenge: M_i changes online, so the planner must react during execution.

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Two-Level Hierarchical Architecture

Global layer (static map)

- Computes a waypoint route from start to goal.
- Enforces safety margin via clearance map.
- Post-process: line-of-sight sparsification, wall-pushing.

Local layer (online, reactive)

- Plans inside observation window ($r = 2 \Rightarrow 5 \times 5$).
- Avoids moving obstacles, tracks current global waypoint.
- Triggers global replanning when stuck.

Global Planners (Waypoints)

- **Grid BFS**: shortest in number of grid steps (8-connected), with safety margin.
- **Grid DFS**: lower memory; not guaranteed shortest.
- **A***: $f(n) = g(n) + h(n)$; uses Manhattan heuristic with diagonal moves enabled (not always optimal).
- **Dijkstra**: optimal distances; slower (worst-case $O(|V|^2)$ in this implementation).

Post-processing: clearance map (multi-source BFS), Bresenham line-of-sight sparsification, wall pushing.

Local Planners (Reactive Navigation)

- **Reactive BFS**: BFS in local observation graph (fast, robust).
- **Reactive DFS**: DFS locally (can be brittle under dynamics).
- **Potential Field**: attractive + repulsive forces, mapped to 4-connected action.
- **Greedy**: choose locally improving action (myopic; can get stuck).

Stuck Detection & Replanning

Execution loop monitors:

- No-motion events and no-progress events to current waypoint.
- If stuck counter exceeds threshold (typically 15 steps in benchmark):
    - Trigger **global replanning** from current position to final goal.
    - Reset waypoint index and continue.

Consistent safety margins: global margin typically 2 cells; local obstacle inflation typically 1 cell.

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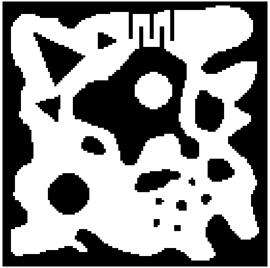
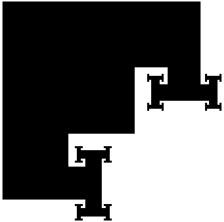
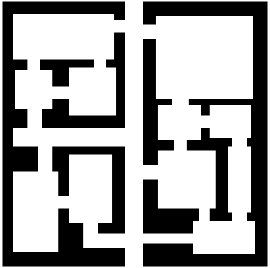
Benchmark Setup

- 7 maps, obstacle counts $\{0, 50, 100, 200\}$.
- 16 combinations: 4 global $\times$ 4 local planners $\Rightarrow 448$ runs.
- Observation radius $r = 2$ $(5 \times 5$ window); local inflation margin 1.
- Stop: 2000 steps or 100 seconds; success when Manhattan distance to goal ≤ 3.

Benchmark Maps

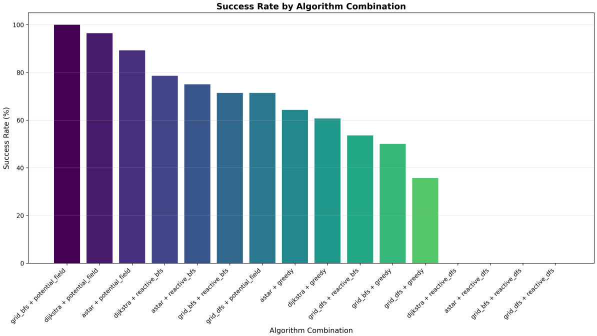





Overall Results (448 runs)

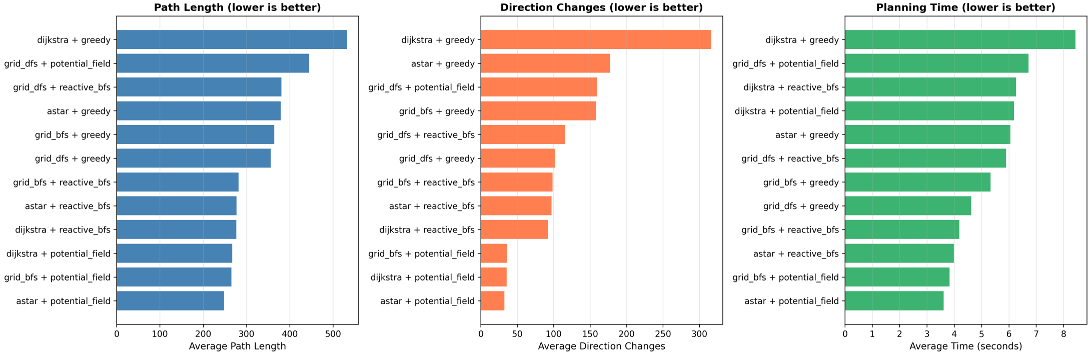
- Total success: **237/448** $\Rightarrow$ **52.9%**.
- Successful runs: average path length **327.10** $\pm$ **243.60** cells.
- Successful runs: average runtime **5.3429** $\pm$ **5.1084** seconds.



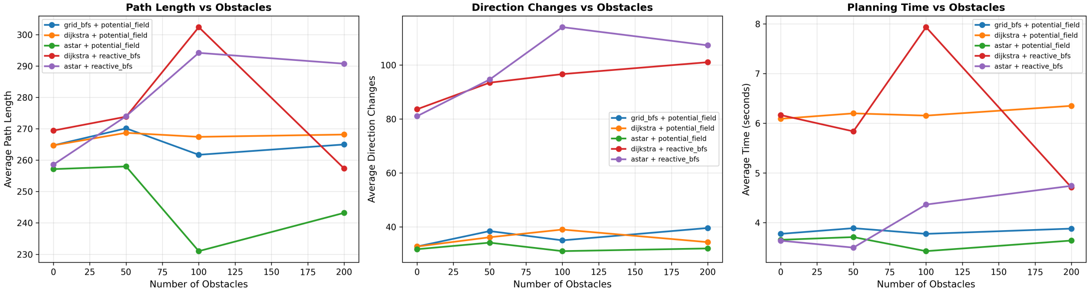
Key Finding: Local Method Dominates Reliability

- **Potential field** combinations rank highest in success rate.
- **Reactive BFS** is competitive but consistently below potential field.
- **Greedy** gives mid-range success.
- **Reactive DFS fails across all globals** (0/28 per combination).

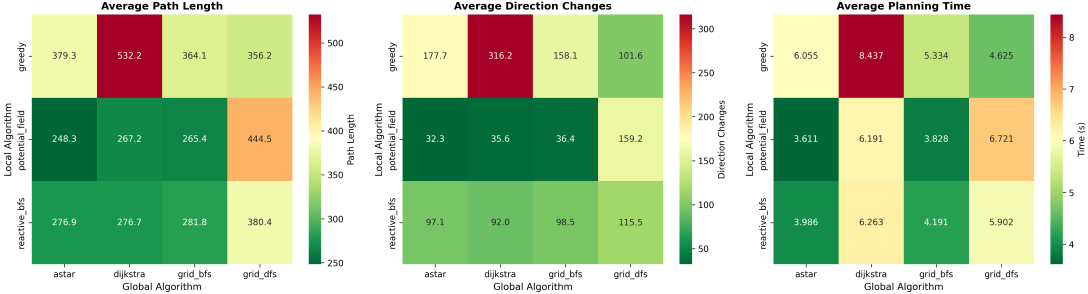
Path Quality & Runtime (Successful Runs)



Impact of Obstacle Density



Heatmap Summary (Averages)



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Conclusions

- A hierarchical **global waypoint + local reactive** planner works well under moving obstacles.
- In this benchmark, **local planning choice** is the biggest factor for success.
- Potential-field local planning achieves the best overall robustness and trajectory smoothness.

Future work

- Improve local minima handling for potential fields.
- Use admissible heuristic for diagonal A* (e.g., octile distance).
- Stronger dynamic-obstacle prediction and richer action set.

Q & A

Questions?