Towards Time-Optimal Any-Angle Path Planning with Dynamic Obstacles

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1. Problem Statement

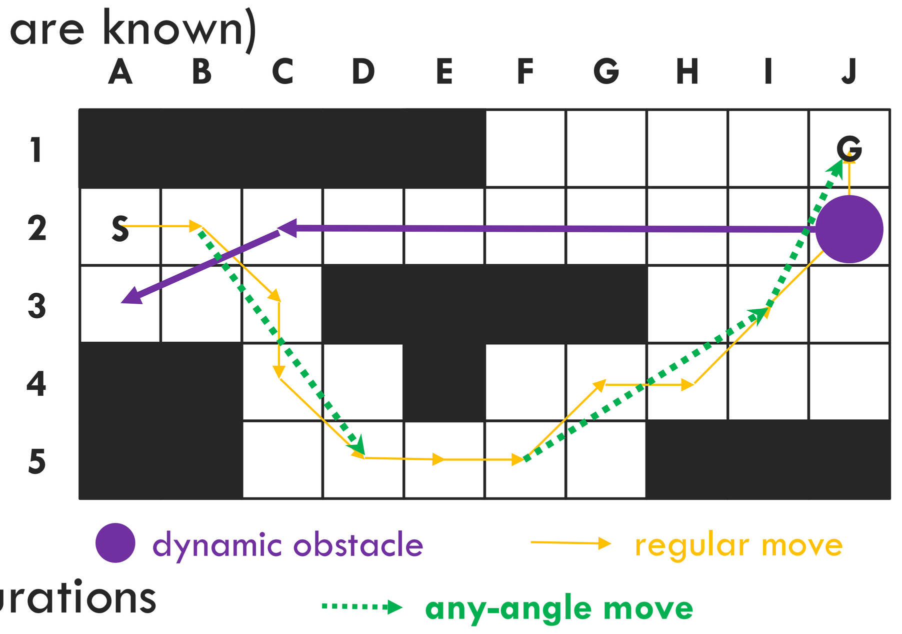
- (V, E) - **graph**, representing the workspace (grid)
- **start** and **goal** locations for **1 agent** (disk of a predefined radius)
- *N* **moving obstacles** (plans are known)

Actions:

- regular move (edge is in E)
- any-angle move (edge is not in E)
- wait (at vertex)

Action cost - duration

Plan cost - sum of actions' durations



Task: Reach the goal *as early as possible* utilizing all available actions

2. Handling Time

Safe Interval Path Planning (SIPP) algorithm [1]

SIPP ~ A* in a different search space

Search node **n** = (**v**, [t_{begin}, t_{end}])

- **v** - graph vertex
- [t_{begin}, t_{end}] - safe interval

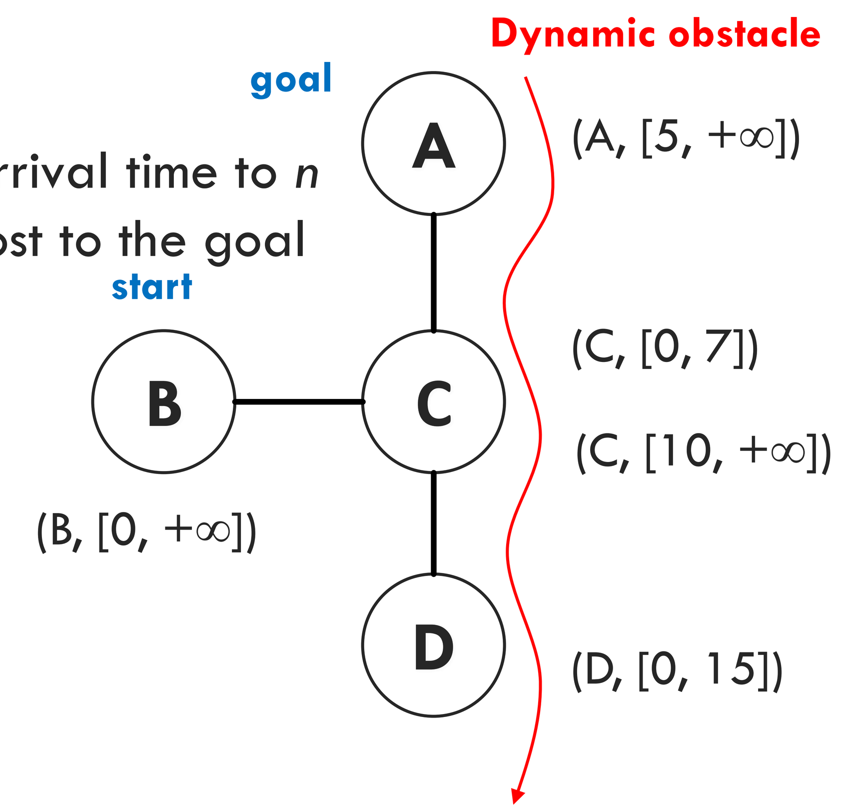
g(n) – the earliest possible arrival time to *n*

h(n) – estimate of the plan cost to the goal

- Admissible
- Consistent

SIPP **properties:**

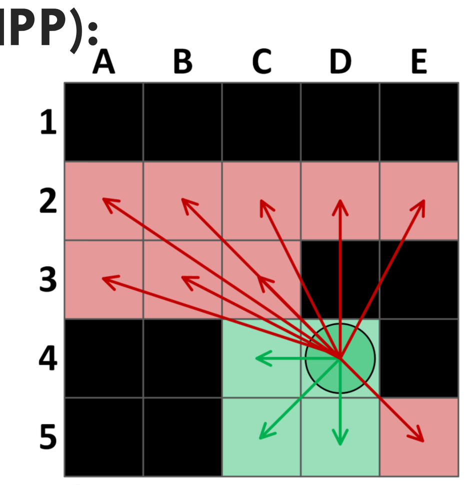
- Complete
- Optimal



3. Handling Any-Angle Moves

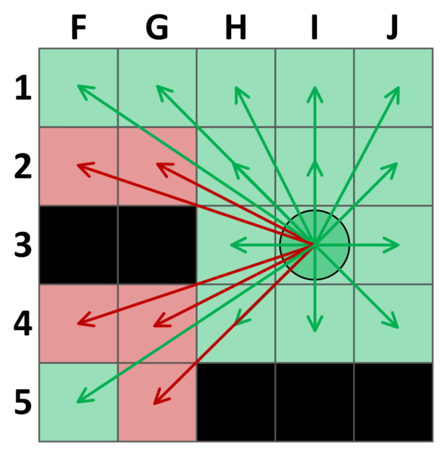
Naïve Time-Optimal AA-SIPP (nTO-AA-SIPP):

- Works as regular SIPP algorithm
- Generates *all* potential successors for a node
- Complete and optimal
- Straightforward
- Computationally expensive



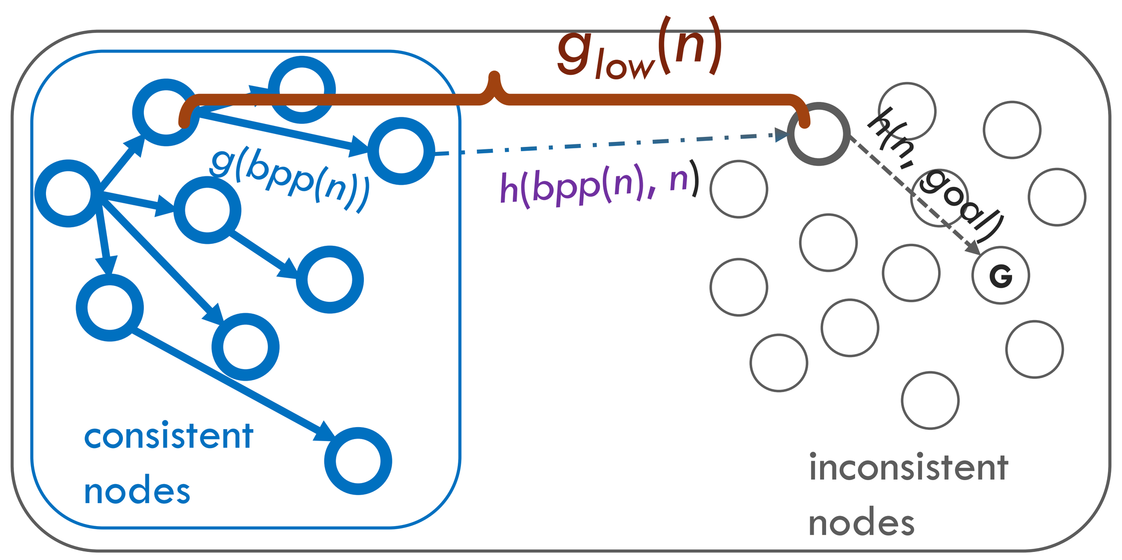
Time-Optimal Any-Angle SIPP With Inverted Expansions (iTO-AA-SIPP):

- Initially generates *all* search nodes
- Performs systematic lazy search
- Makes inverted expansions
- Complete and optimal
- Computationally effective in most of the cases
- In the worst case works as nTO-AA-SIPP



High Level Implementation of iTO-AA-SIPP:

- Choose the most promising inconsistent node ***n*** and its best potential parent ***bpp(n)***
- Try to decrease ***g(n)*** by considering a transition ***bpp(n)*** → ***n***
- Estimate whether ***n*** became consistent. If yes, move it to the set of potential parents
- Repeat until **goal** is not consistent (or all reachable nodes become consistent)



$$f(n) = \left.\begin{array}{l} g(bpp(n)) + \\ h(bpp(n), n) + \\ h(n, goal) \end{array}\right\} g_{low}(n)$$

4. Empirical Evaluation

Maps [2, 3]:

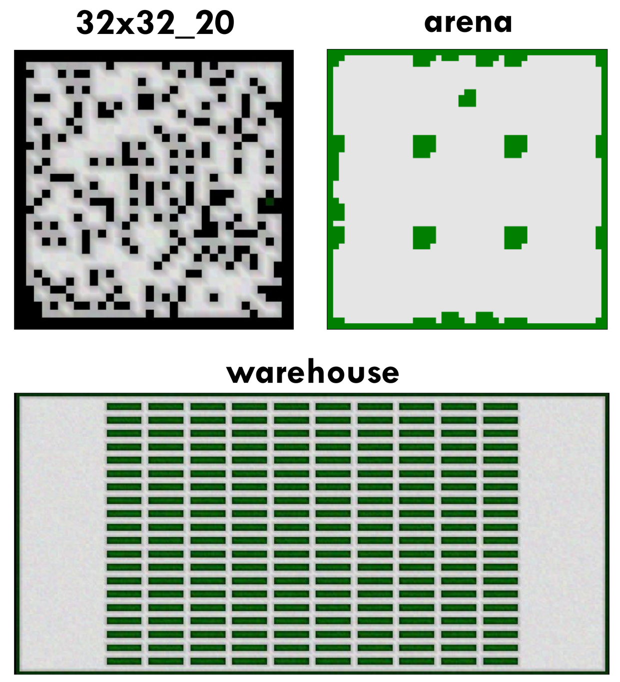
- arena(49x49)
- 32x32_20(32x32, 20% blocked)
- warehouse (170x84)

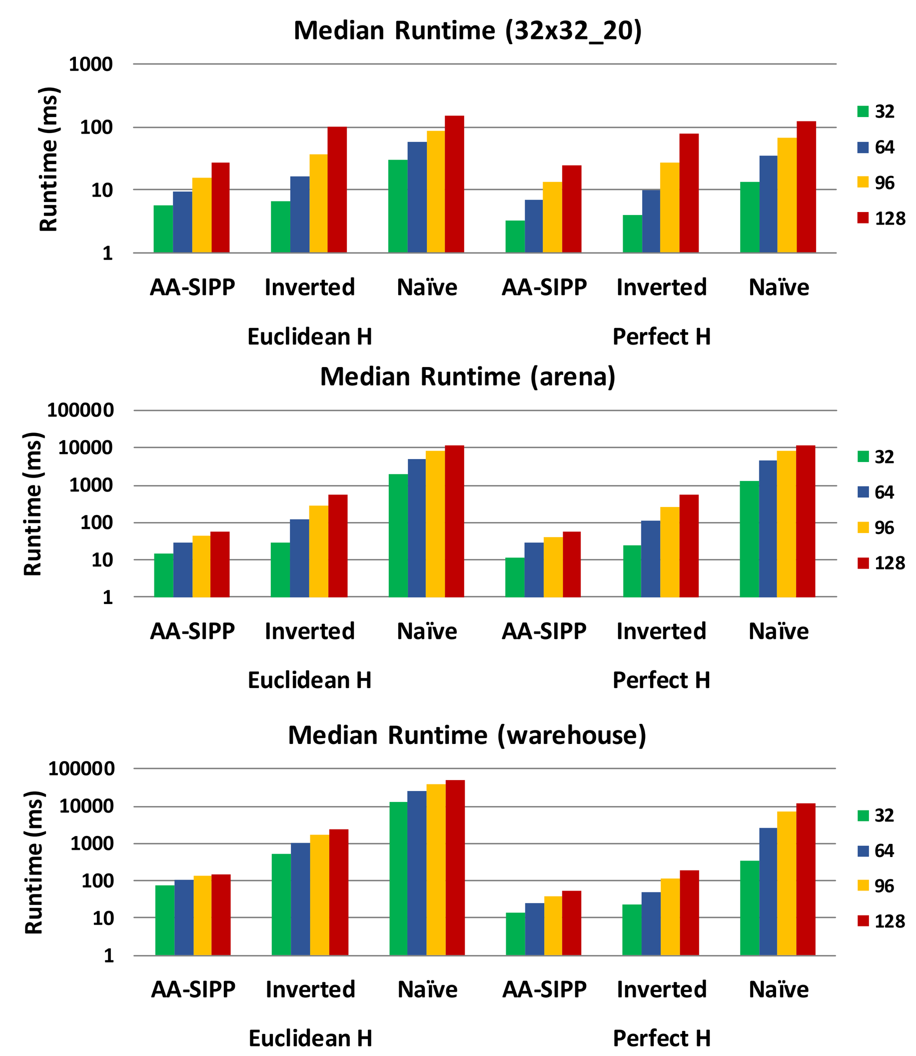
Algorithms:

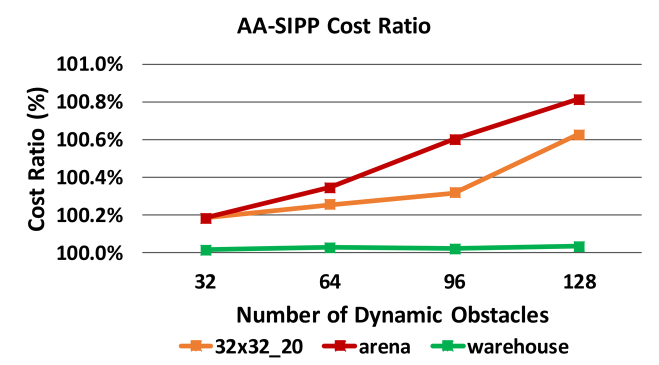
- AA-SIPP (greedy reset parent)[4]
- Naïve (generate all successors)
- Inverted (iTO-AA-SIPP)

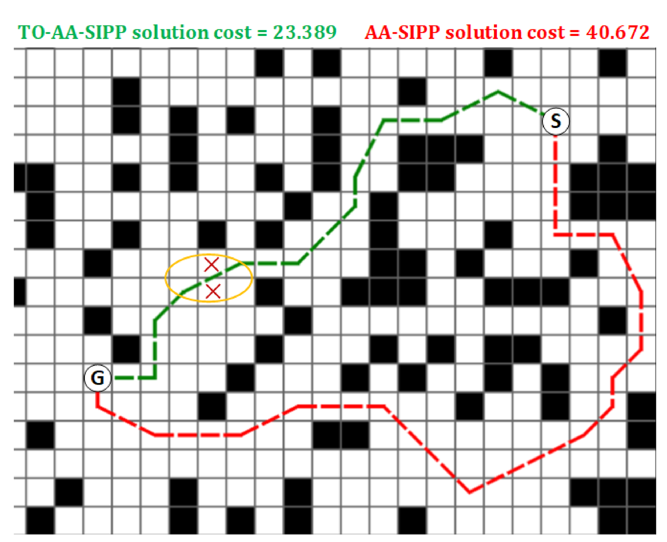
Setup:

- dynamic obstacles: 32, 64, 96, 128
- 500 runs
- 2 heuristics: Euclidean distance and Perfect H (static obstacles)









1) iTO-AA-SIPP is up to **one order of magnitude faster** than nTO-AA-SIPP

2) In some setups iTO-AA-SIPP is comparable to AA-SIPP (32x32_20, small number of obstacles)

3) The average difference in costs between AA-SIPP and TO-AA-SIPP is negligible, while in some certain cases it can be much higher

[1] Phillips, M.; and Likhachev, M. 2011. SIPP: Safe interval path planning for dynamic environments. In Proceedings of The 2011 IEEE International Conference on Robotics and Automation (ICRA 2011), 5628–5635.
[2] Sturtevant, N. 2012. Benchmarks for grid-based pathfinding. IEEE Transactions on Computational Intelligence and AI in Games 4(2): 144–148.
[3] Stern, R.; Sturtevant, N.; Felner, A.; Koenig, S.; Ma, H.; Walker, T.; Li, J.; Atzmon, D.; Cohen, L.; Kumar, T. K.; Boyarski, E.; and Bartak, R. 2019. Multi-Agent Pathfinding: Definitions, Variants, and Benchmarks. In Proceedings of the Symposium on Combinatorial Search (SoCS), 151–158.
[4] Yakovlev, K.; and Andreychuk, A. 2017. Any-Angle Pathfinding for Multiple Agents Based on SIPP Algorithm. In Proceedings of ICAPS 2017, 586–593.

Code (GitHub)