Computation and Use of Topology-based Heuristic Functions for Motion Planning

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Joint work with ***V. Ranganeni, O. Salzman**, **S. Chintalapudi,***
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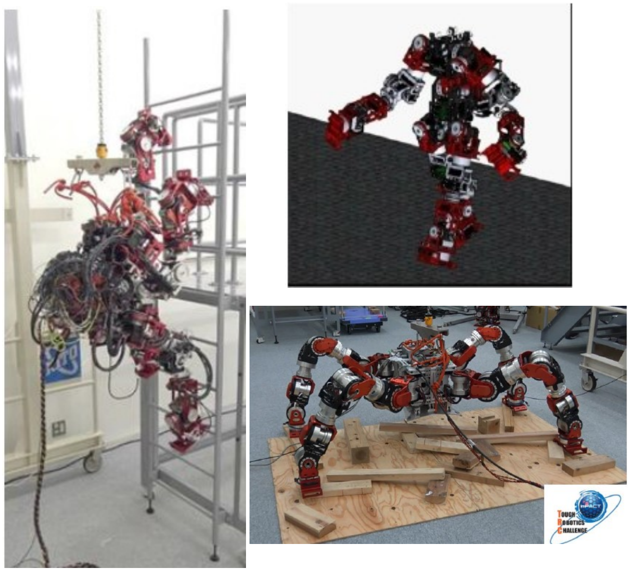
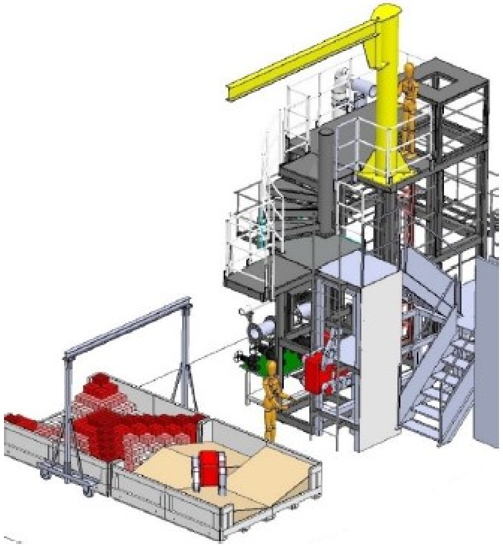
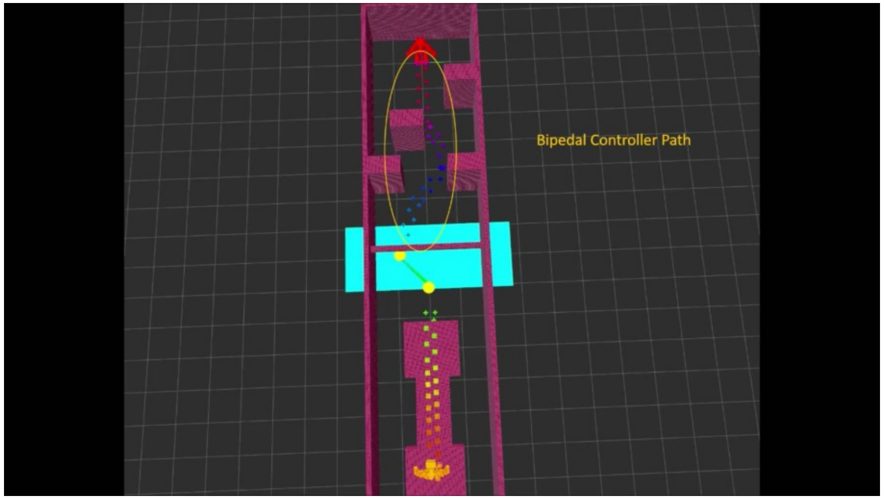
Motivation for Topology-based Heuristics

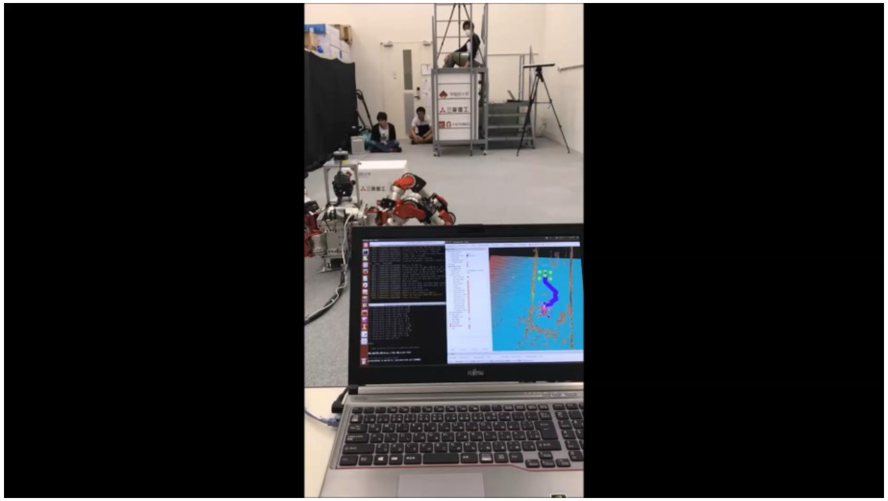
- Single-planner approach to humanoid planning [Dornbush et al., ICRA'18]



Waseda/Mitsubishi robot







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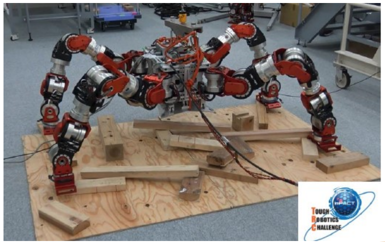

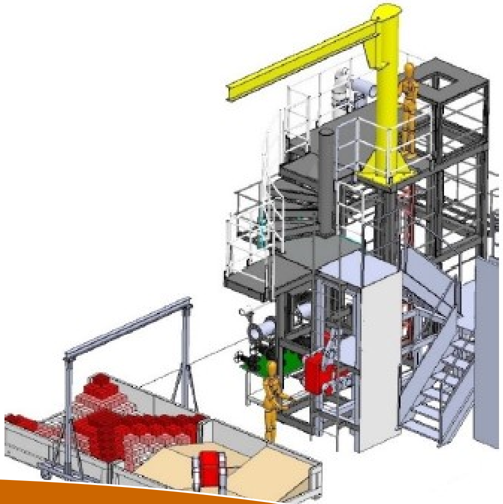

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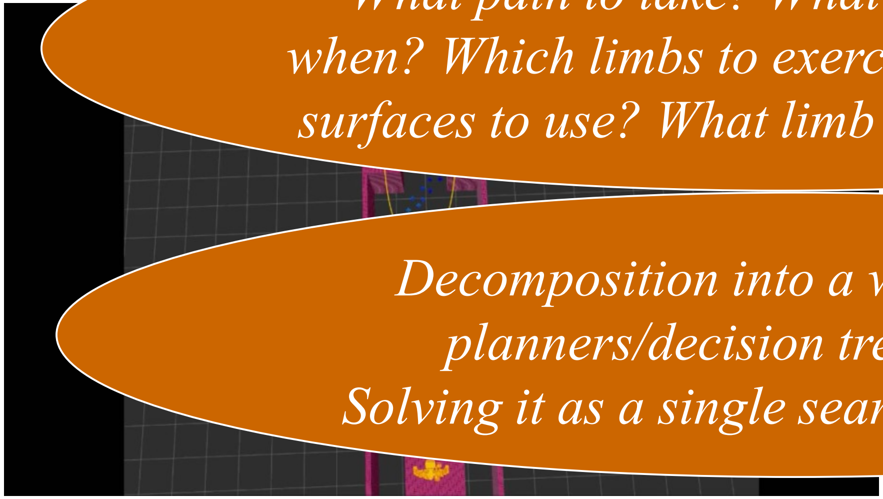
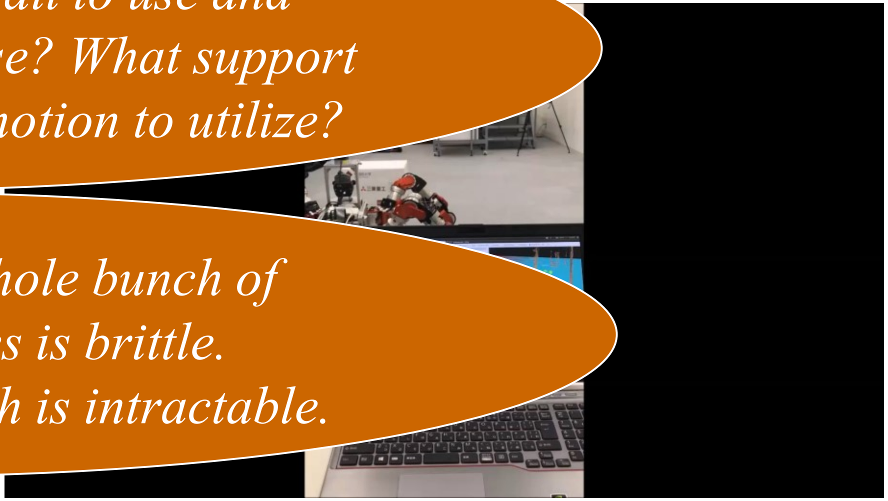
What path to take? What gait to use and when? Which limbs to exercise? What support surfaces to use? What limb motion to utilize?





Decomposition into a whole bunch of planners/decision trees is brittle.
Solving it as a single search is intractable.

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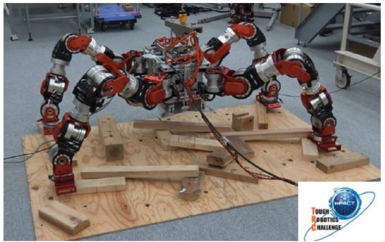
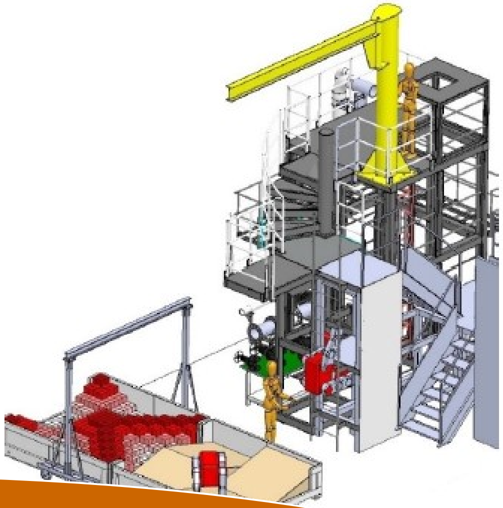
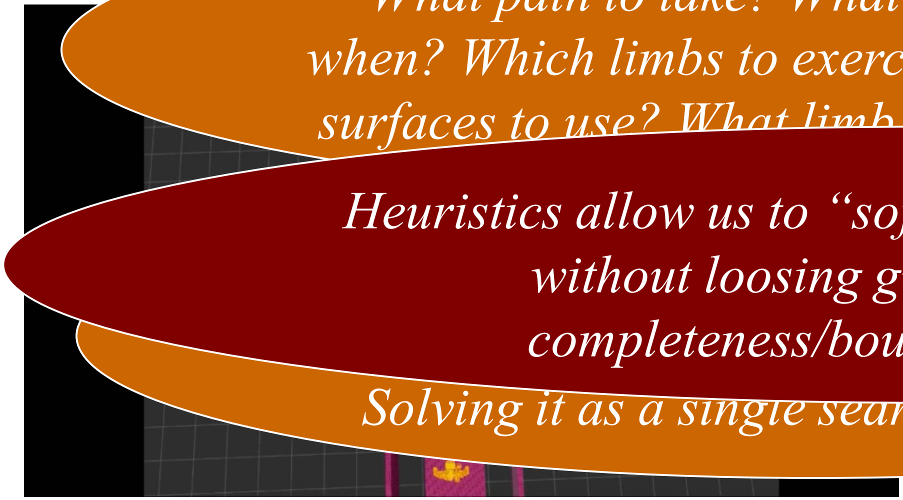






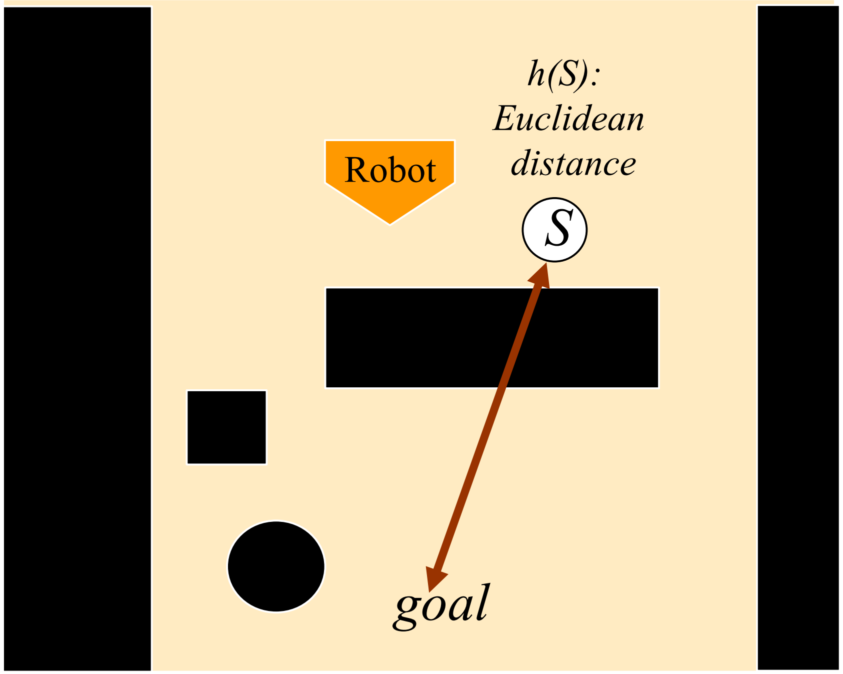
What path to take? What gait to use and when? Which limbs to exercise? What support surfaces to use? What limb motion to utilize?

Solving it as a single search is intractable.

Heuristics allow us to “softly” decompose the problem without loosing guarantees on global completeness/bounded sub-optimality

What are Heuristic Functions?

- Heuristic values in A*-like planning = estimates of the cost-to-goal
- A*-like planning (e.g., weighted A*, etc.) biases its search efforts along the gradient given by the heuristic function while maintaining guarantees on completeness and bounded sub-optimality



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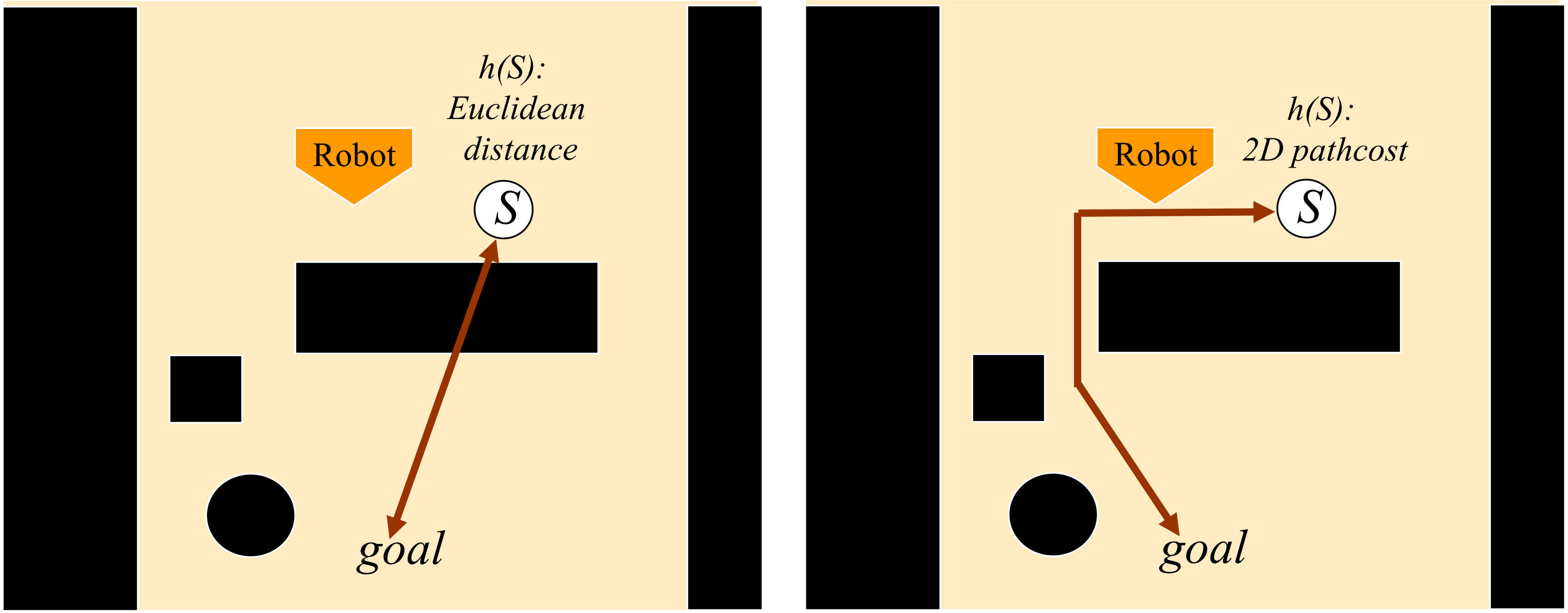

- Heuristics based on 2D solution costs often provide “good” gradients

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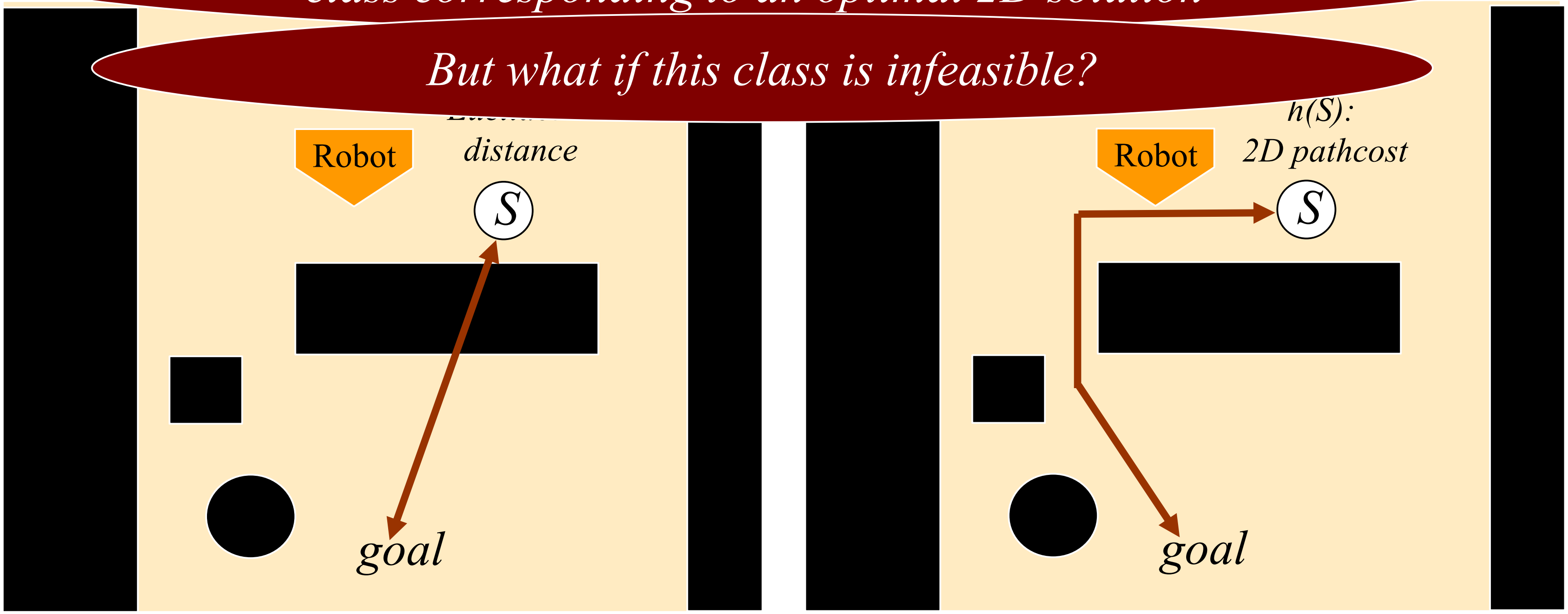
such heuristic function guides planning along a topological class corresponding to an optimal 2D solution

But what if this class is infeasible?



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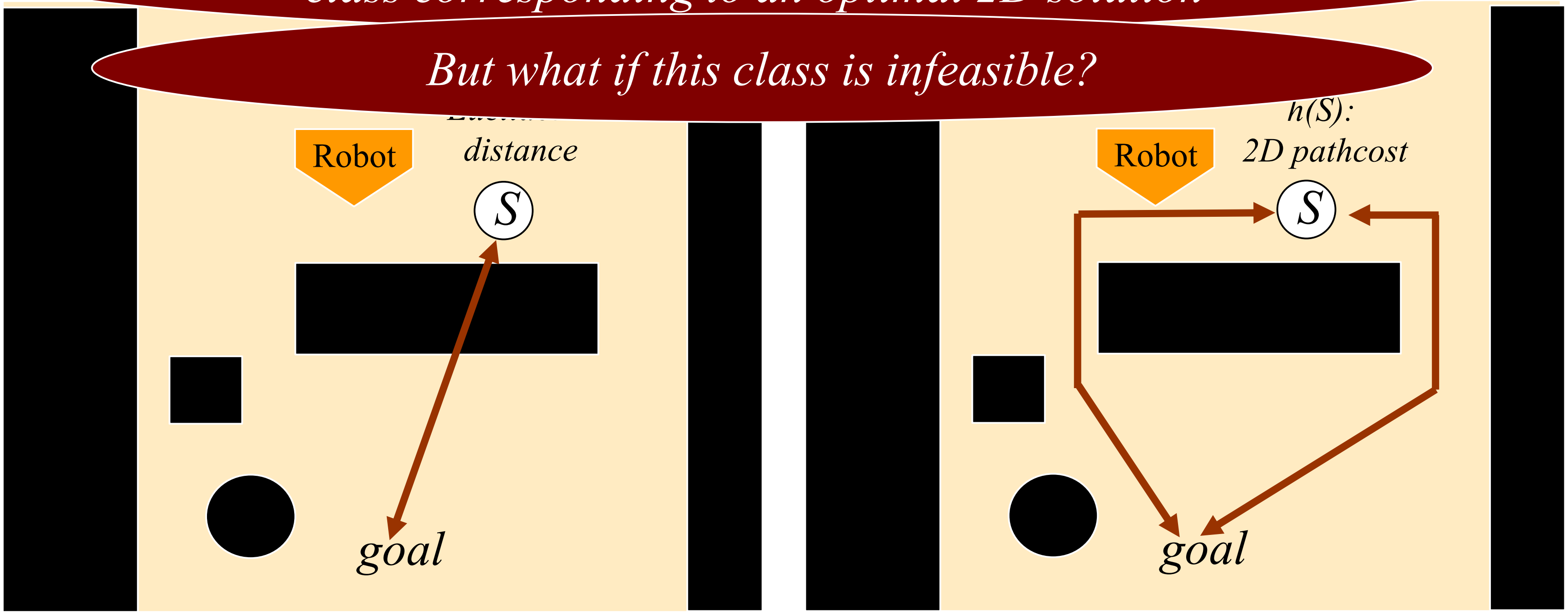
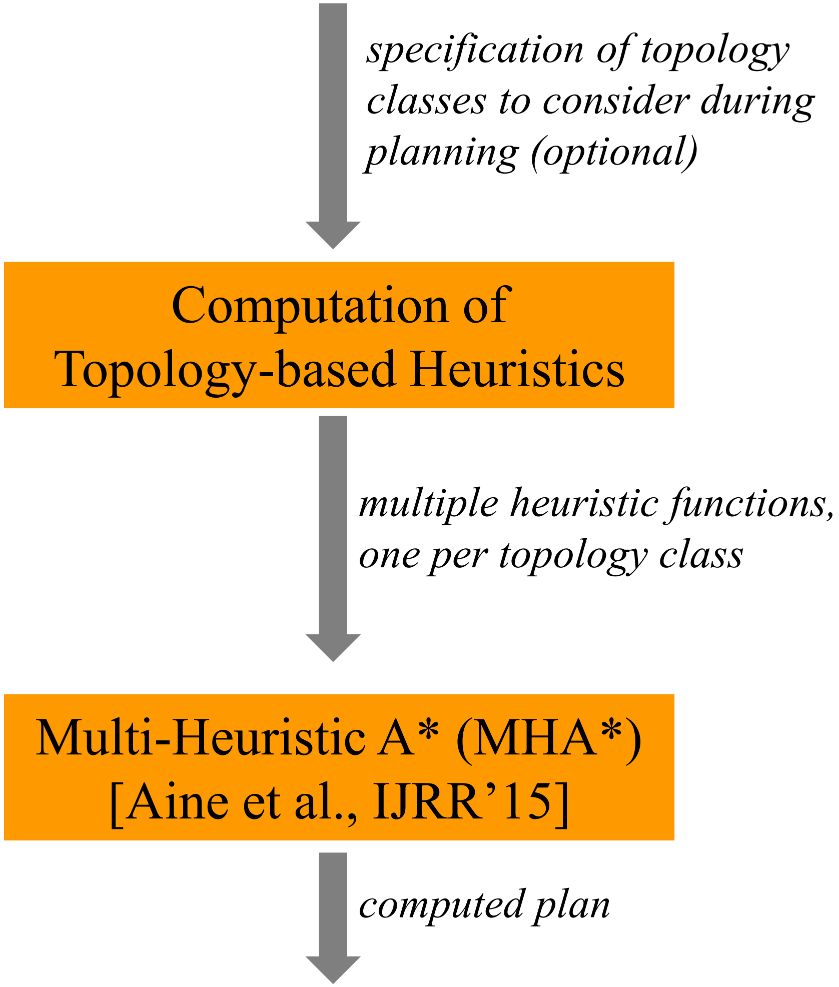


The planner needs to be capable of using ***multiple*** *heuristic functions simultaneously!*

Use of Multiple Topology-based Heuristics



specification of topology classes to consider during planning (optional)

Computation of Topology-based Heuristics

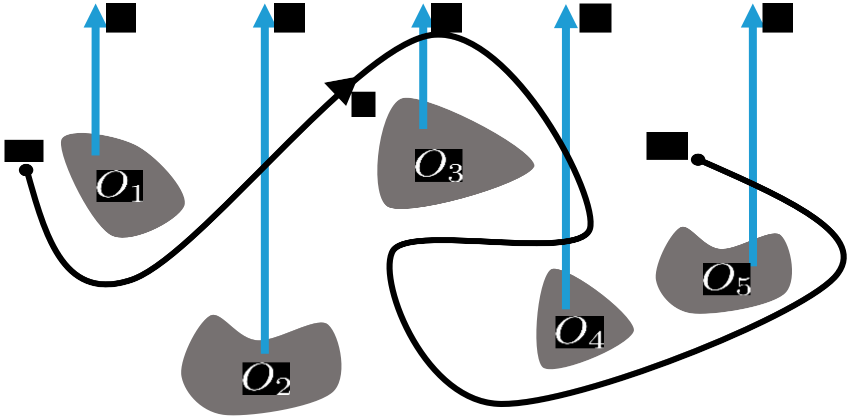
multiple heuristic functions, one per topology class

Multi-Heuristic A* (MHA*) [Aine et al., IJRR’15]

computed plan

Use of Multiple Topology-based Heuristics

Use Beams [Tovar et al., '09] to define topology signature in 2D



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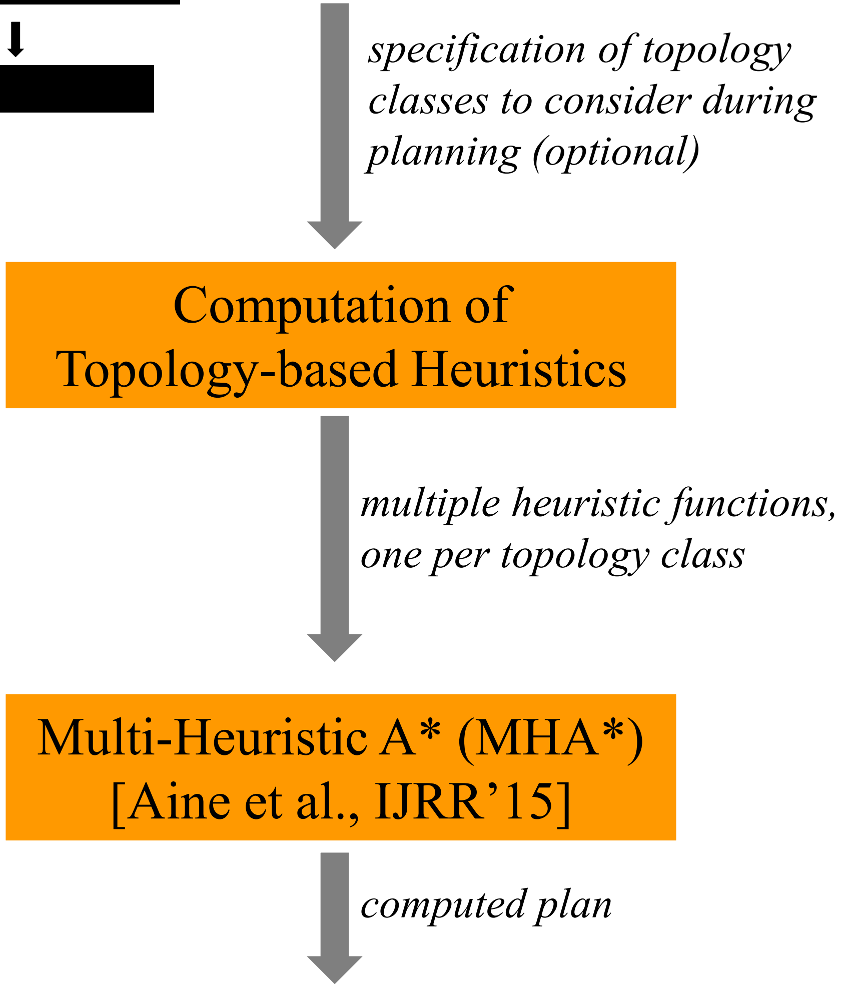
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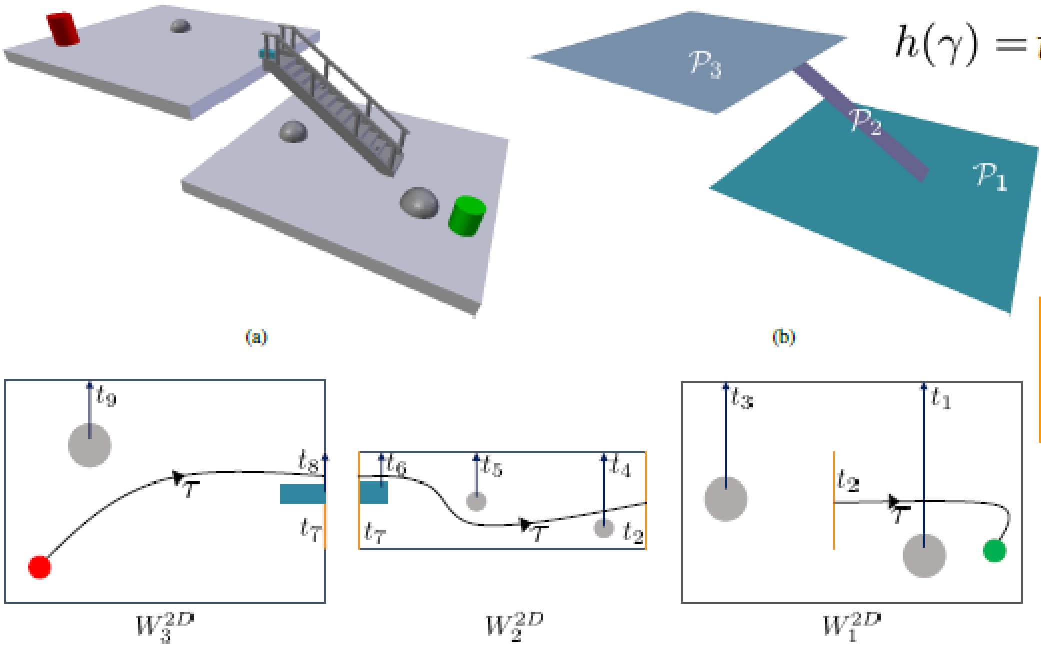
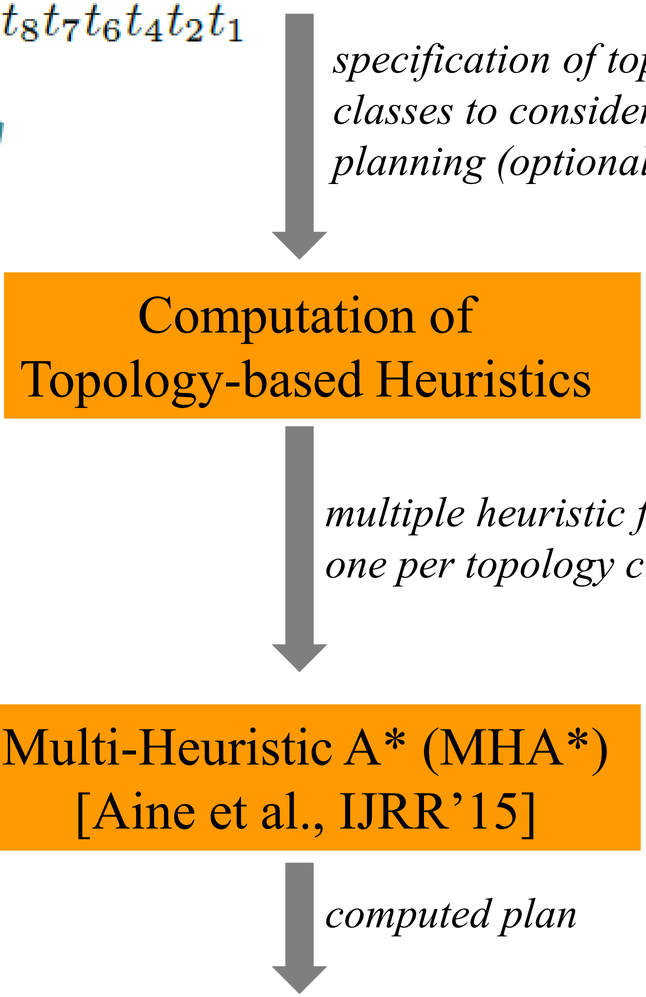
Use of Multiple Topology-based Heuristics

Use Beams and Gates [Ranganeni et al., in submission] to define topology signature in 2.5D

$$h(\gamma) = t_8\bar{t_7}t_6t_4\bar{t_2}t_1$$





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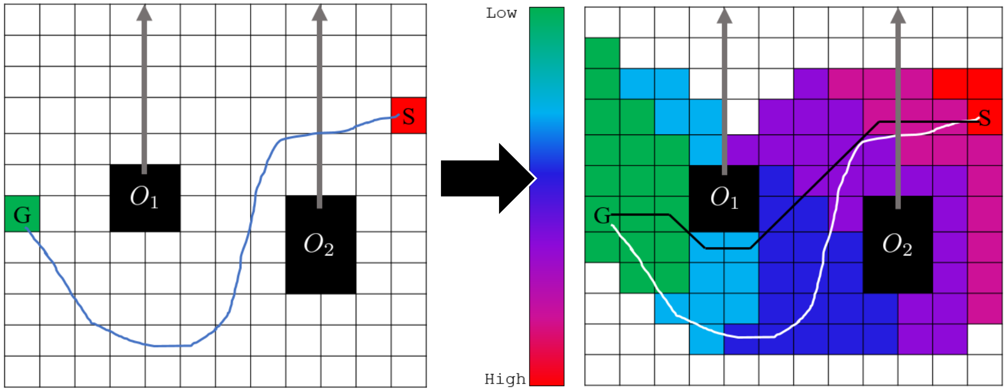
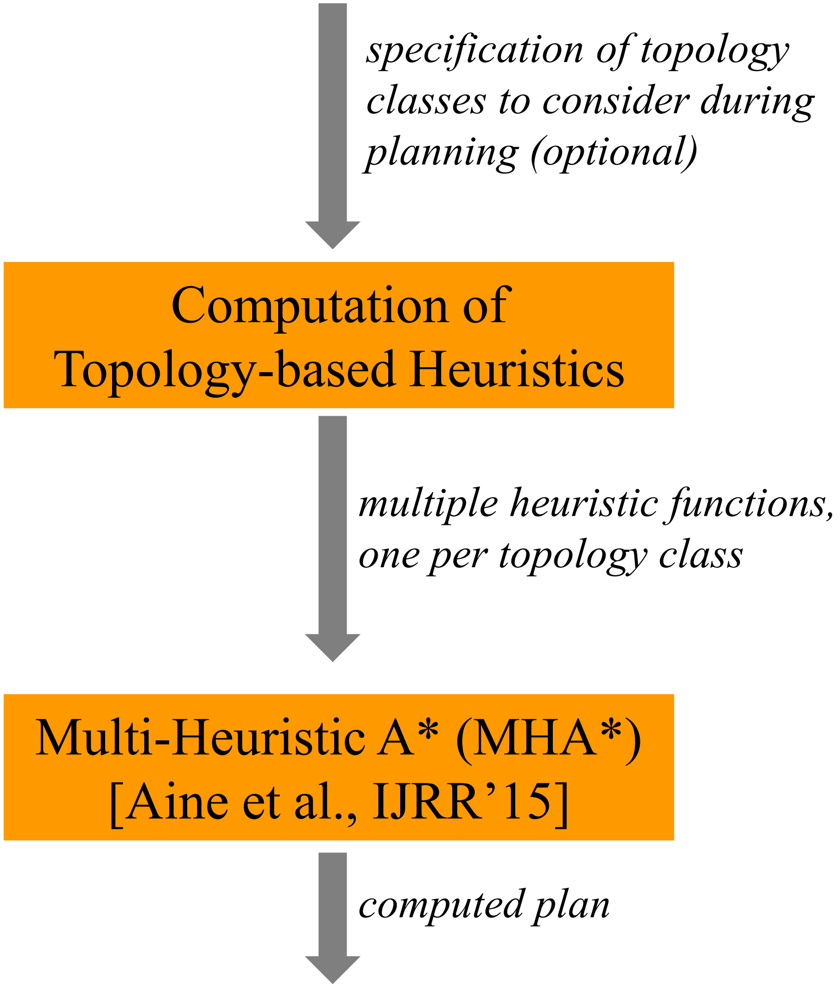
Use of Multiple Topology-based Heuristics

Runs a single Dijkstra's search backwards from the goal on graph G, where each vertex v is defined by (x,y,h(γ))





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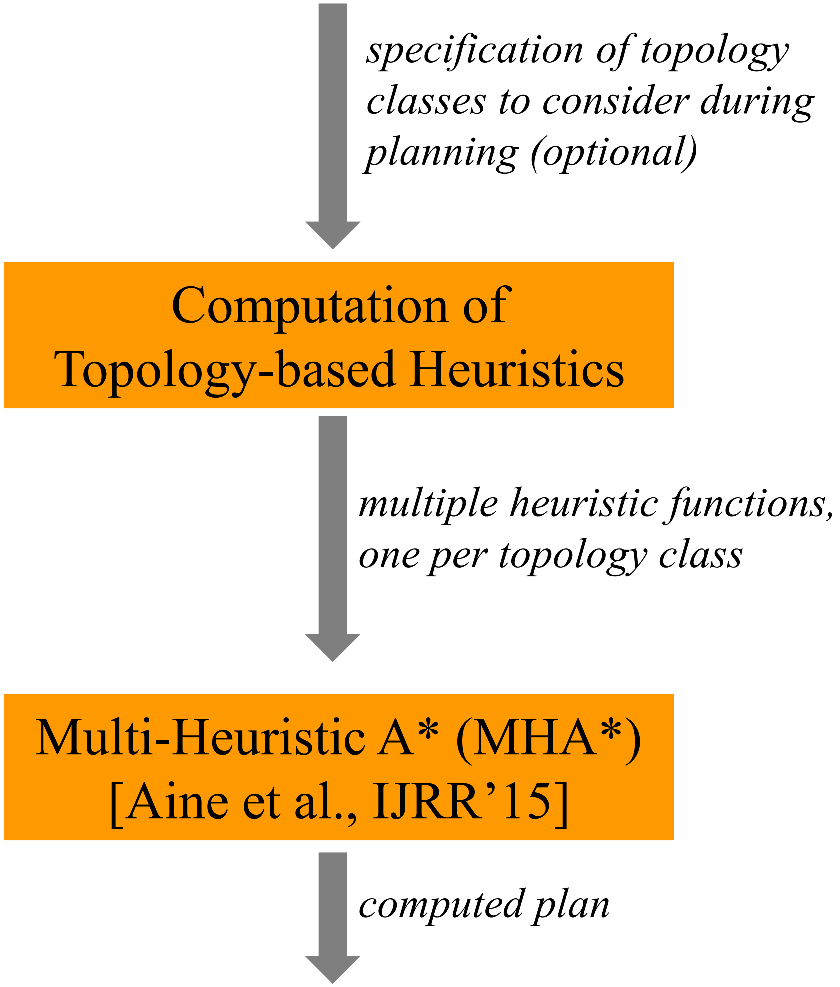

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computed plan

Runs MHA search forward (from start) guided by computed heuristic functions on:*

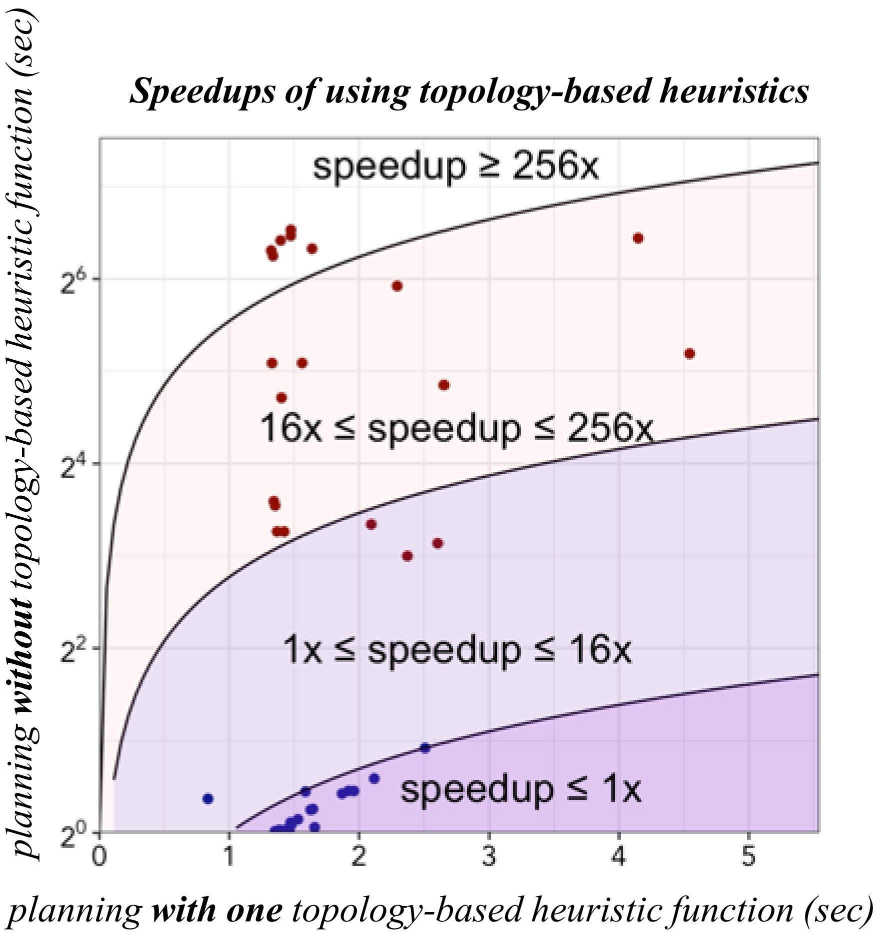
- original graph where each vertex v is defined by q_{full}

OR

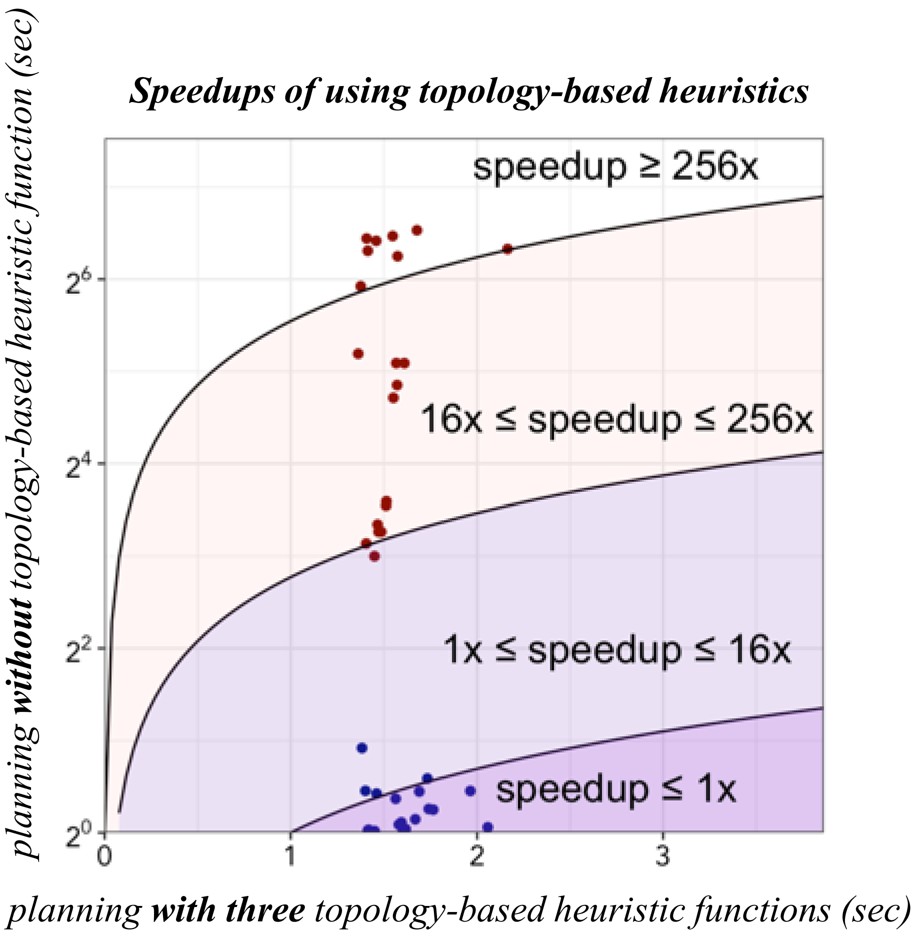
- augmented graph where each vertex v is defined by $(q_{full},h(\gamma))$

Benefits of Topology-based Heuristics

- Footstep planning for humanoid [*Ranganeni et al., ICAPS'18*]



Speedups of using topology-based heuristics



Speedups of using topology-based heuristics

● *complex queries* ● *simple queries*

Potential Future Directions

- Automatically figuring out what topology classes to consider for computing heuristics
- Dynamically instantiating new topology-based heuristics
- Understanding when planning hits a local minimum and a new topological class needs to be explored

Thanks

- Students/postdocs who contributed:
  - V. Ranganeni
  - O. Salzman
  - S. Chintalapudi
  - A. Dornbush
  - K. Vijayakumar
  - S. Bardapurkar
  - F. Islam
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  - ONR
  - ARL
  - NSF