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Euclidean Pathfinding with Compressed Path Databases IJCAI 2020

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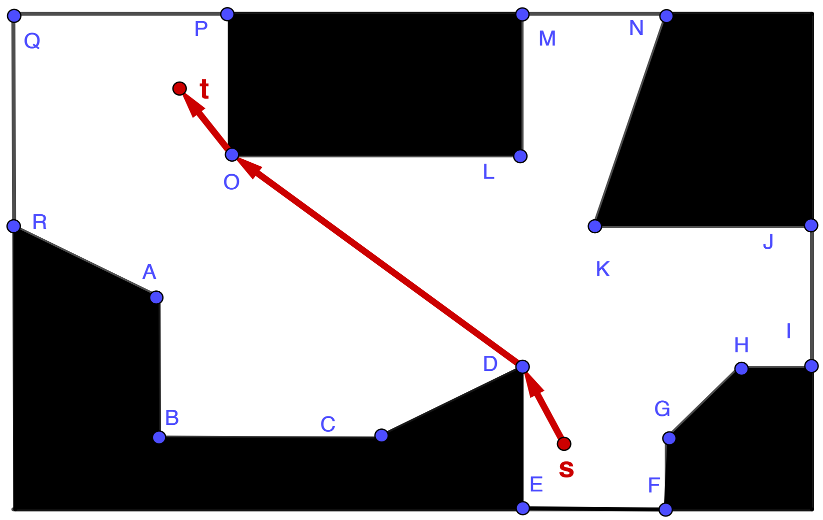
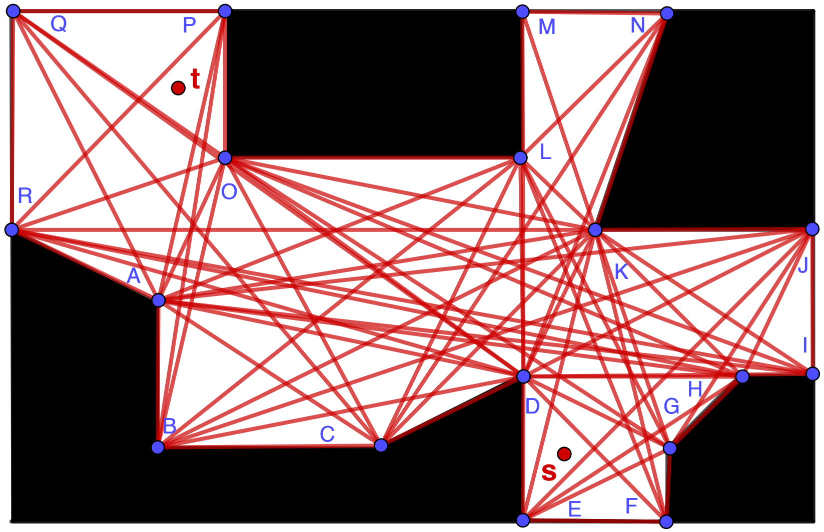
Euclidean Shortest Path Problem

- Euclidean plane:
  - Polygonal obstacles
    - A set of vertices
    - A set of closed edges
- Pathfinding:
  - Given a start s and target t
  - Optimal non-obstructed path.

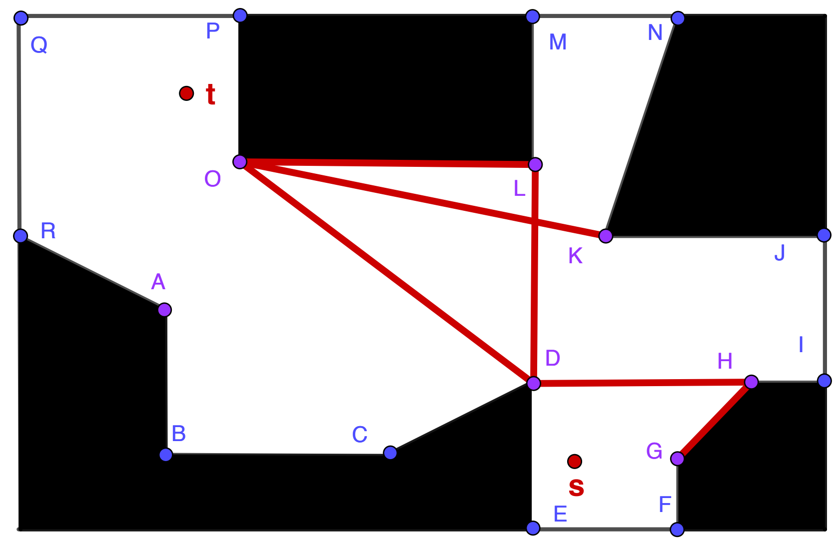


- Visibility graph [1] :
  - Connecting co-visible vertices

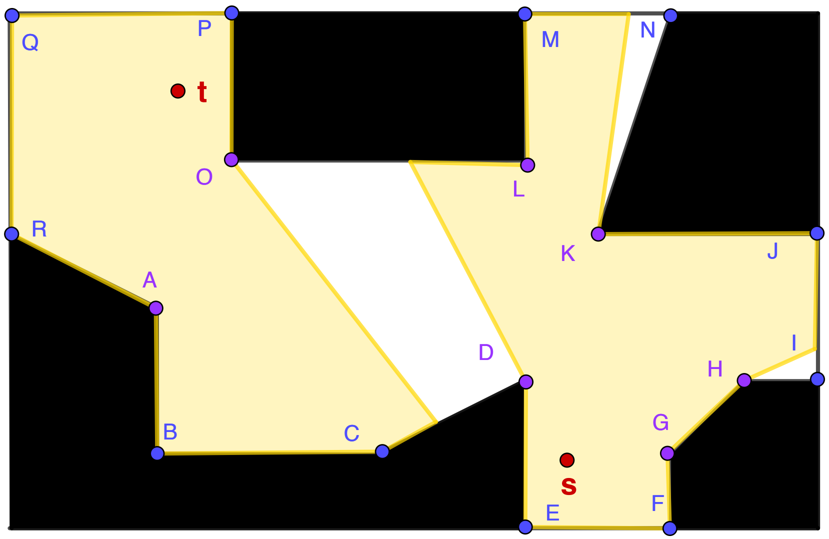


Sparse visibility graph [2]

- Visibility graph [1]
- Sparse visibility graph [2] :
  - Remove unnecessary vertices and edges



- Visibility graph [1]
- Sparse visibility graph [2]
- Pathfinding:
  - Full insertion
  - Heuristic search



Shaded yellow areas correspond to the area visible from s and t

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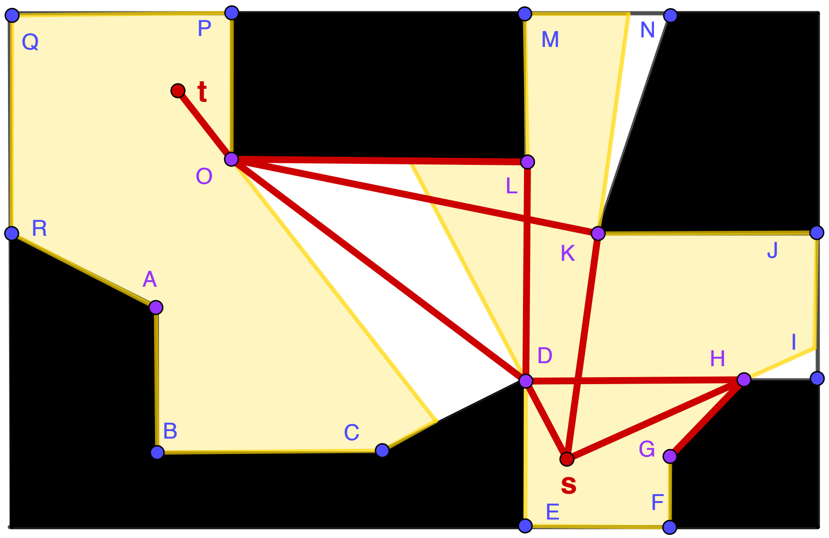

Shaded yellow areas correspond to the area visible from s and t

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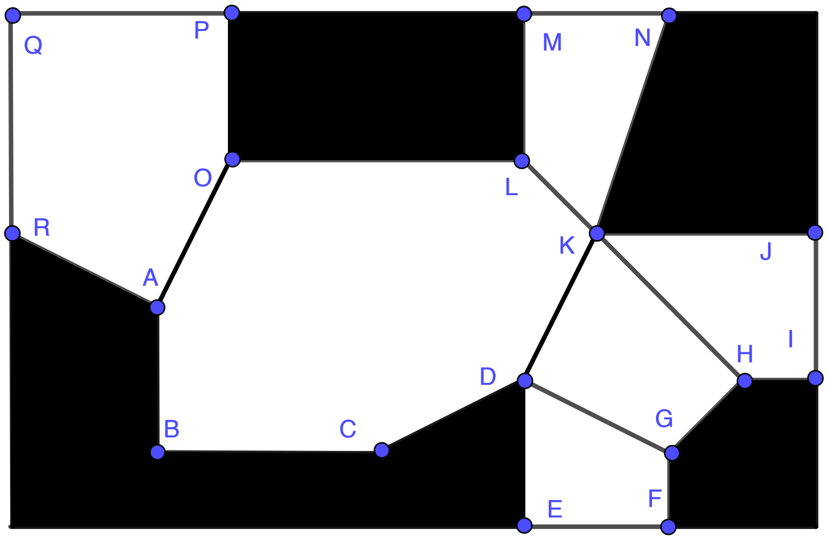
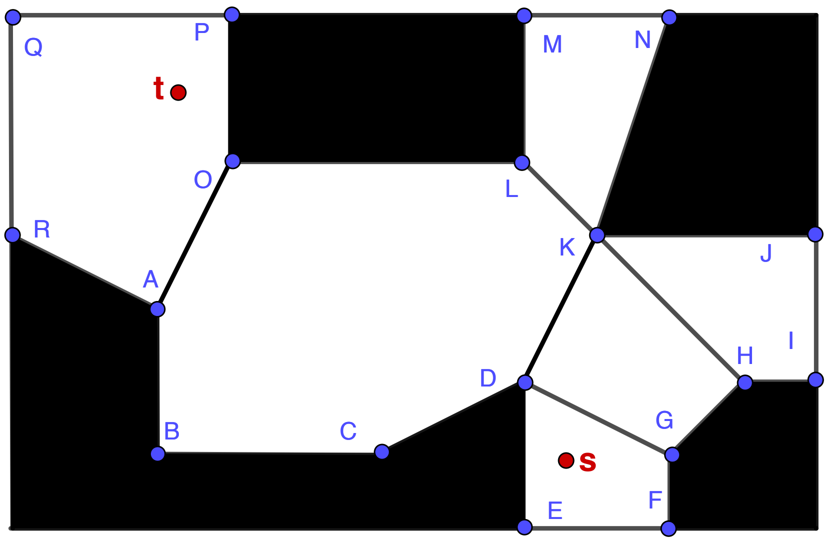
- Navigation Mesh

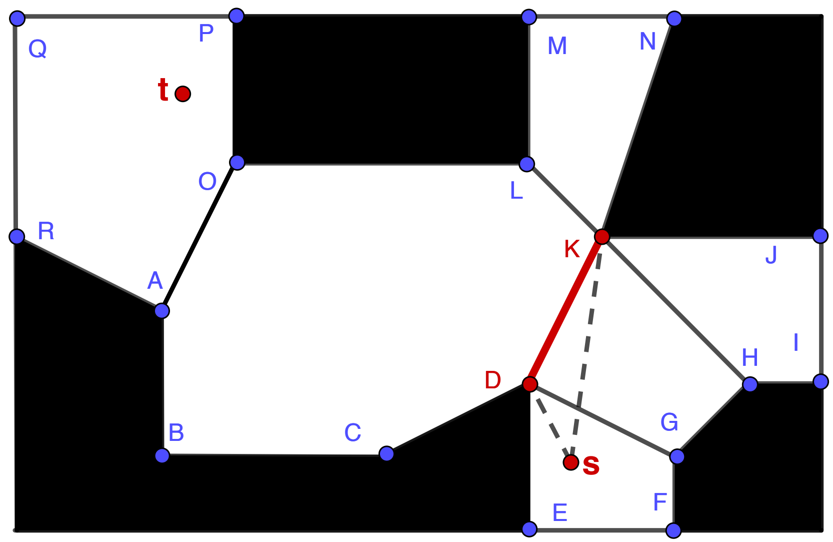


Mesh-based Planner
Polyanya [3]

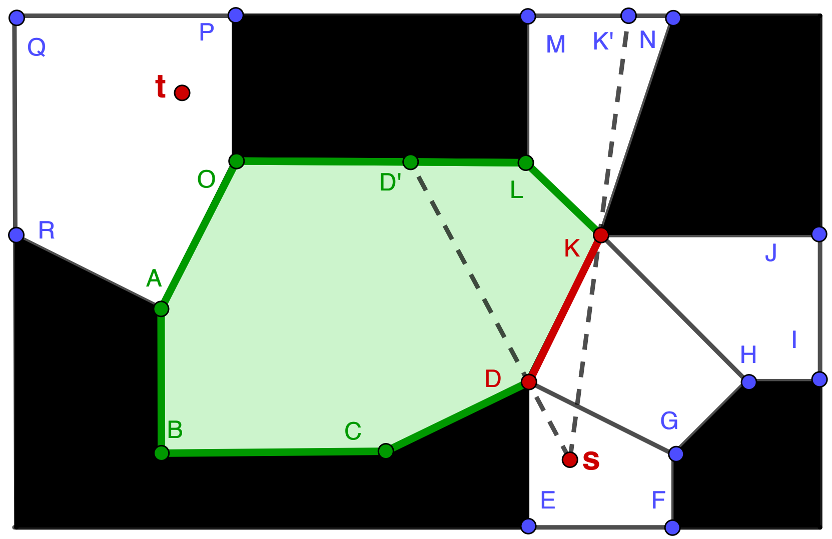
- Navigation Mesh
- Polyanya [3]
  - Search Nodes
  - Successors
  - Evaluation Function



- Navigation Mesh
- Polyanya [3]
  - Search Nodes:
    - Interval & Root
      - i.e. ([D,K] , s)

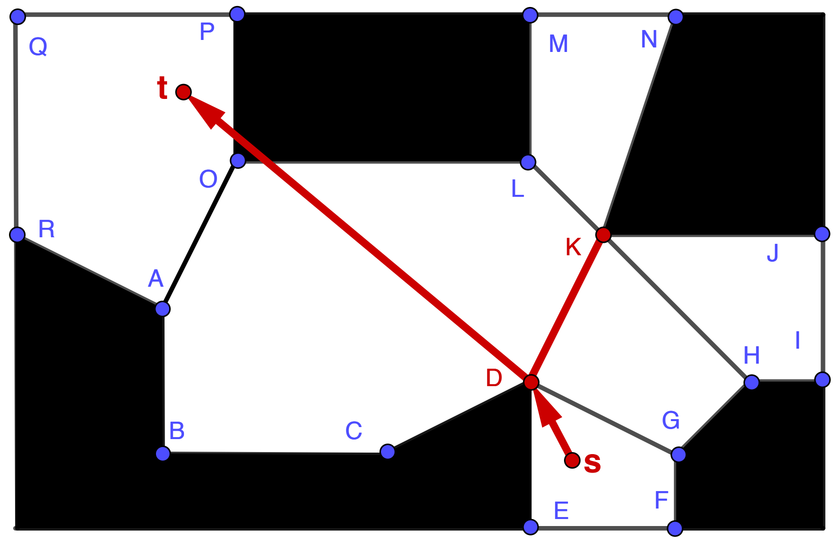


- Navigation Mesh
- Polyanya [3]
  - Search Nodes:
    - Interval & Root
  - Successors:
    - Observable Successors
      - i.e. ([L,K] , s)
    - Non-observable Successors
      - i.e. ([A,O] , D)



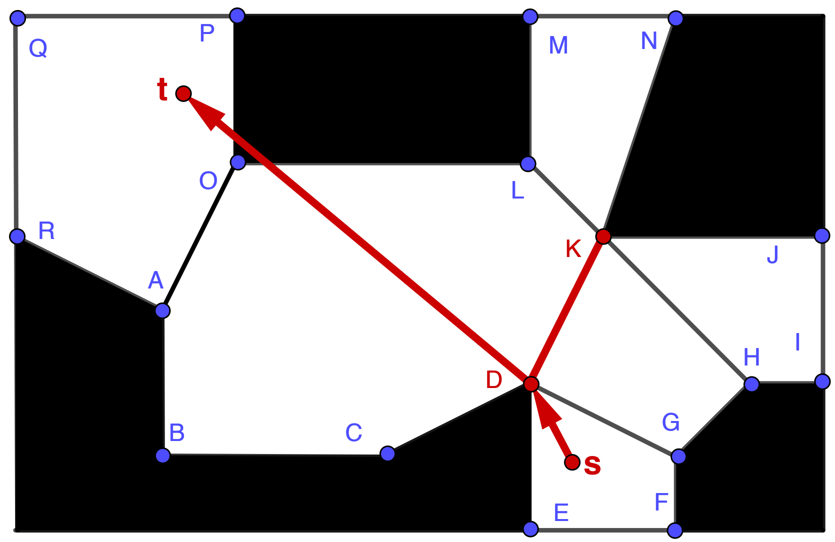
Node expansion in Polyanya. When the current node ([D,K],s) is expanded, it generates the observable successors ([D',L],s), and ([L,K],s); and non-observable successors ([D',O],D), ([O,A],D), ([A,B],D) , ([B,C],D), and ([C,D],D).

- Navigation Mesh
- Polyanya [3]
  - Search Nodes:
    - Interval & Root
  - Successors:
    - Observable Successors
    - Non-observable Successors
  - Evaluation Function:
    - $f(n) = g(n) + h(n)$
      - i.e. $h(n) = d(s,D) + d(D,t)$



Mesh-based Planner
Polyanya [3]

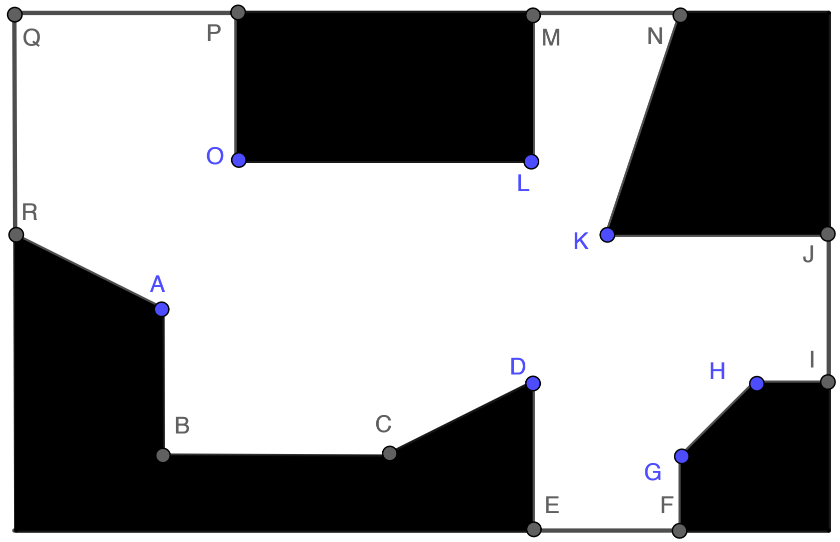
- Navigation Mesh
- Polyanya [3]
  - Search Nodes:
    - Interval & Root
  - Successors:
    - Observable Successors
    - Non-observable Successors
  - Evaluation Function:
    - f(n) = g(n) + h(n)
  - Pathfinding:
    - Depends on the number of polygons expanded and the number of edges on each polygon



Compressed Path Databases (CPD) [4]

- Euclidean-based CPD:
  - First Move Table:
    - Convex vertices

Ordering	A	D	G	H	K	L	O
A	A	D	D	H	K	L	O
D	A	D	G	H	K	L	O
G	D	D	G	H	K	L	O



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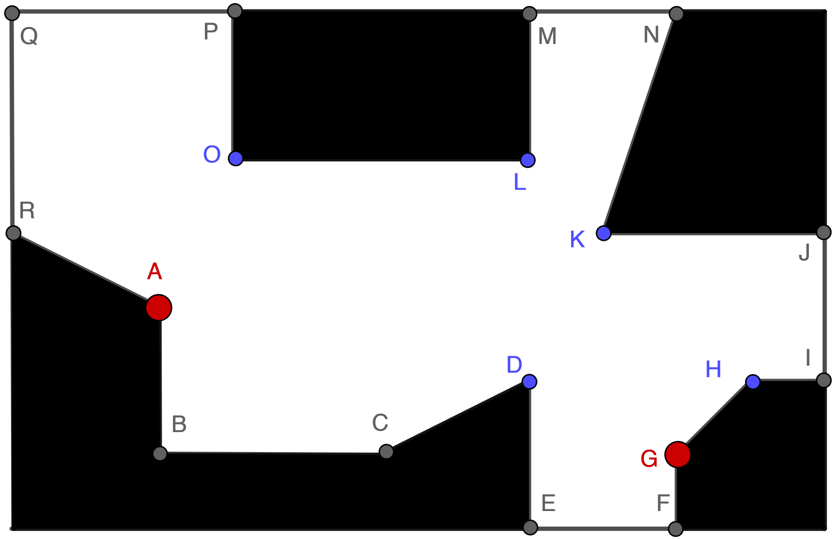

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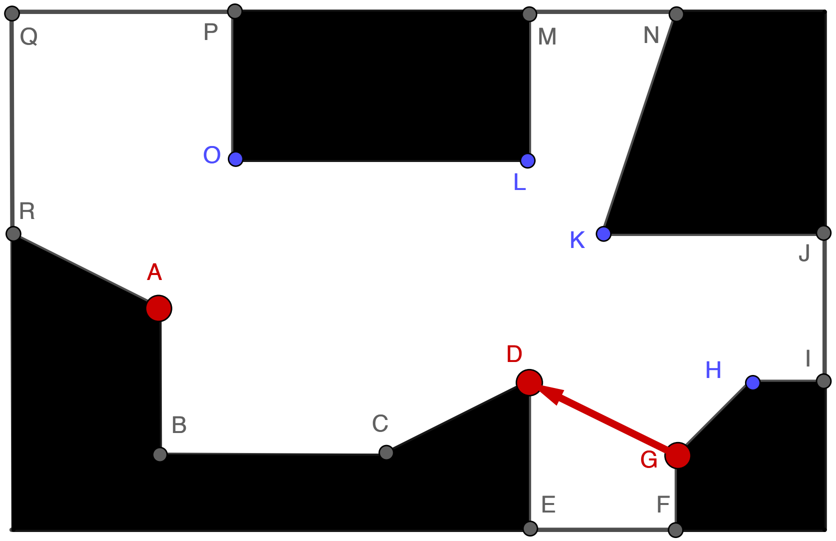

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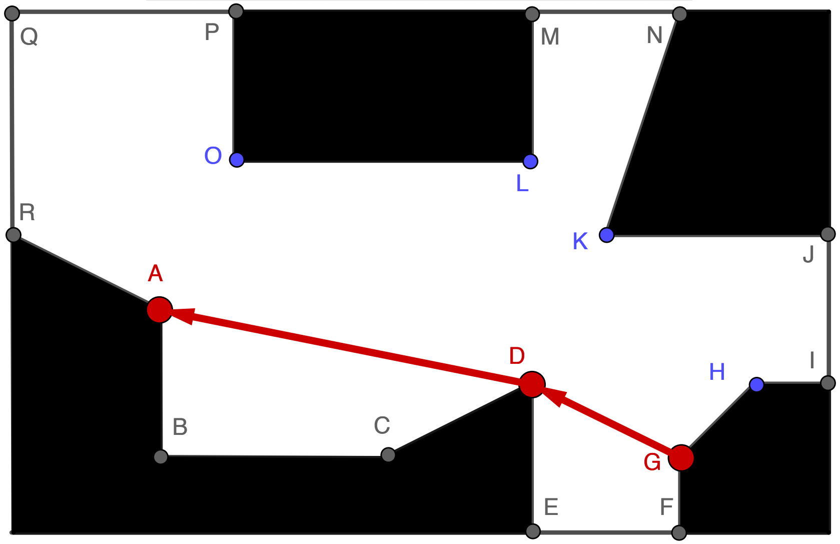
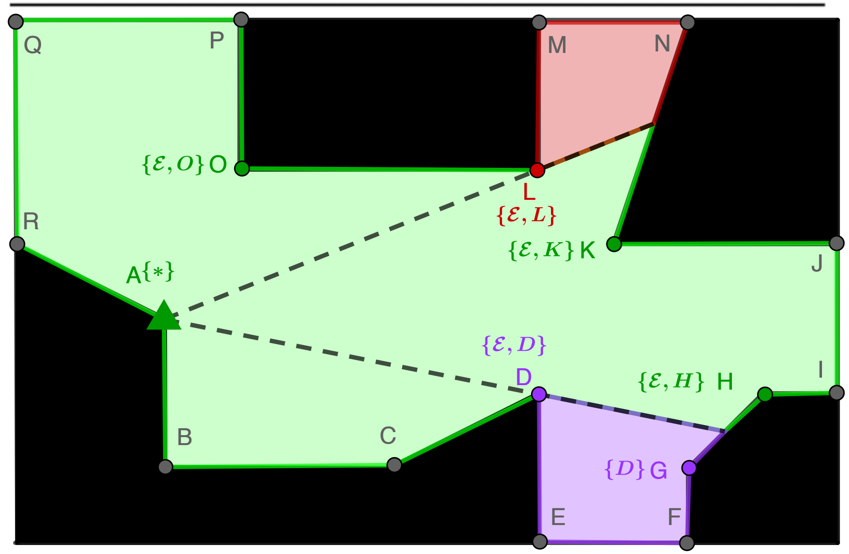


Compressed Path Databases (CPD) [4]

- Euclidean-based CPD:
  - First Move Table:
    - Convex vertices
  - Symbols:
    - [A – R]: indicates the optimal first move

Ordering	A	D	G	H	K	L	O
A	*	{$\mathcal{E}$,D}	$\boxed{\text{D}}$	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
D	{$\mathcal{E}$,A}	*	{$\mathcal{E}$,G}	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
G	D	{$\mathcal{E}$,D}	*	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}



Green area corresponds to the area visible from the source node A. The first move on the optimal path from A to any node in the purple (resp. red) area is D (resp. L).

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- Euclidean-based CPD:
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    - [A – R]: indicates the optimal first move
    - Ɛ: indicates two vertices are directly visible

Ordering	A	D	G	H	K	L	O
A	*	$\boxed{\mathcal{E}}$,D}	D	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
D	{$\mathcal{E}$,A}	*	{$\mathcal{E}$,G}	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
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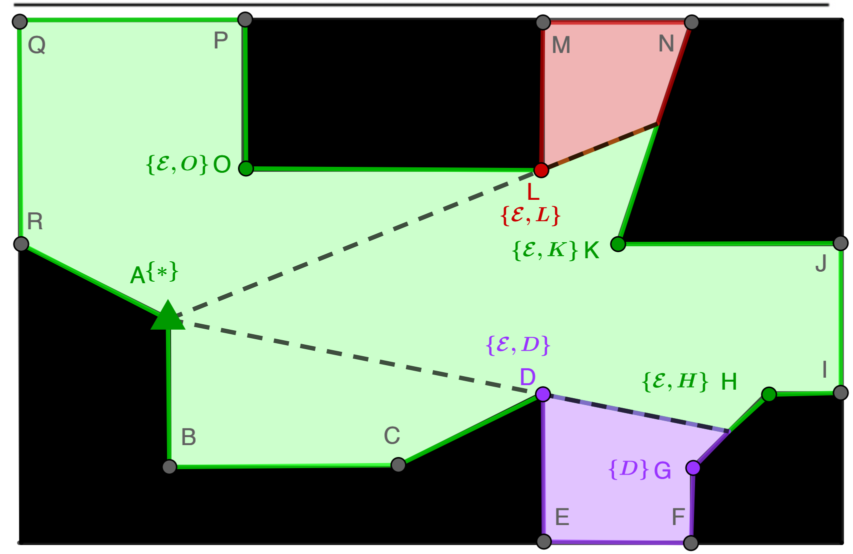

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    - $\mathcal{E}$: indicates two vertices are directly visible
    - {$\mathcal{E}$,D}: redundant symbol [5]

Ordering	A	D	G	H	K	L	O
A	*	$\boxed{\{\mathcal{E},D\}}$	D	$\{\mathcal{E},H\}$	$\{\mathcal{E},K\}$	$\{\mathcal{E},L\}$	$\{\mathcal{E},O\}$
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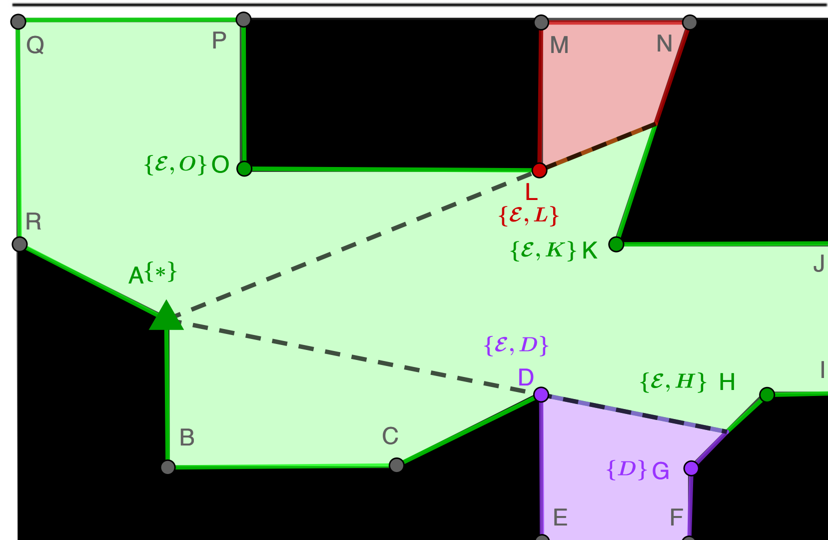

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A	*	$\{\mathcal{E}$,D$\}$	D	$\{\mathcal{E}$,H$\}$	$\{\mathcal{E}$,K$\}$	$\{\mathcal{E}$,L$\}$	$\{\mathcal{E}$,O$\}$
D	$\{\mathcal{E}$,A$\}$	*	$\{\mathcal{E}$,G$\}$	$\{\mathcal{E}$,H$\}$	$\{\mathcal{E}$,K$\}$	$\{\mathcal{E}$,L$\}$	$\{\mathcal{E}$,O$\}$
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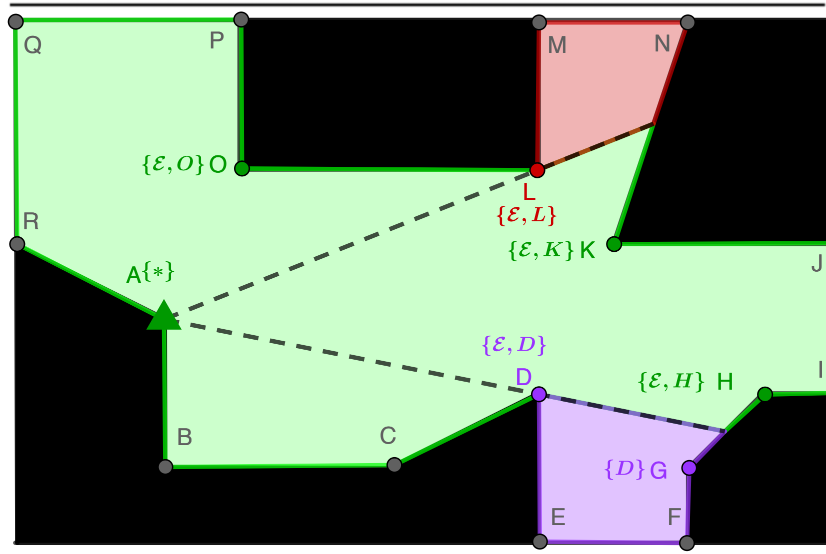

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  - Compression:
    - Depth first search ordering [4]

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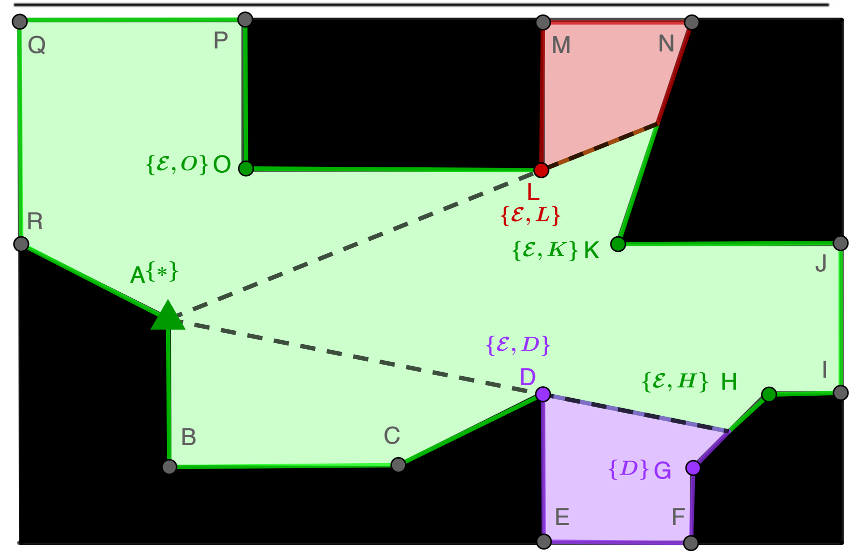

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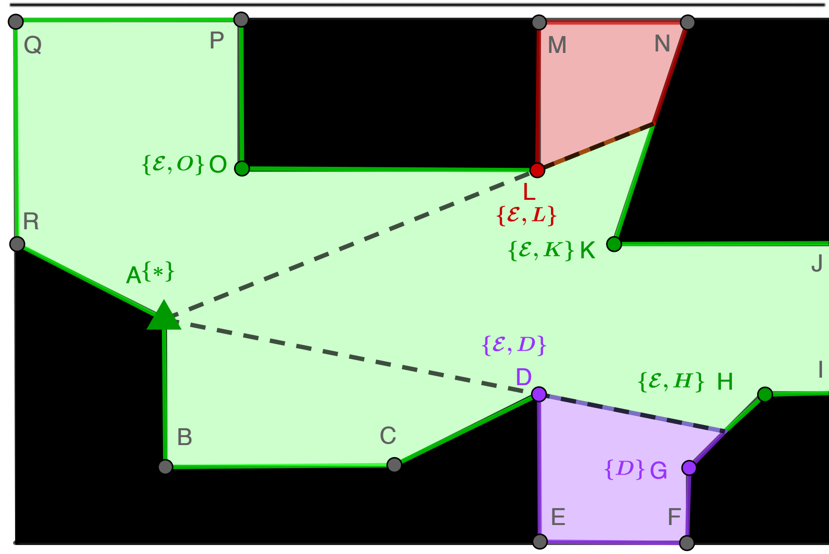
  - Compression:
    - Depth first search ordering [4]
    - Run length encoding [4]
      - (i.e. Row A: 1D; 4Ɛ)

Ordering	A	D	G	H	K	L	O
A	*	{Ɛ,D}	D	{Ɛ,H}	{Ɛ,K}	{Ɛ,L}	{Ɛ,O}
D	{Ɛ,A}	*	{Ɛ,G}	{Ɛ,H}	{Ɛ,K}	{Ɛ,L}	{Ɛ,O}
G	D	{Ɛ,D}	*	{Ɛ,H}	{Ɛ,K}	{Ɛ,L}	{Ɛ,O}



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    - {Ɛ,D}: redundant symbol [5]
    - *: wildcard Symbol [5]
  - Compression:
    - Depth first search ordering [4]
    - Run length encoding [4]
  - First Move Extraction:
    - A simple binary search

Ordering	A	D	G	H	K	L	O
A	*	{$\mathcal{E}$,D}	D	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
D	{$\mathcal{E}$,A}	*	{$\mathcal{E}$,G}	{$\mathcal{E}$,H}	{$\mathcal{E}$,K}	{$\mathcal{E}$,L}	{$\mathcal{E}$,O}
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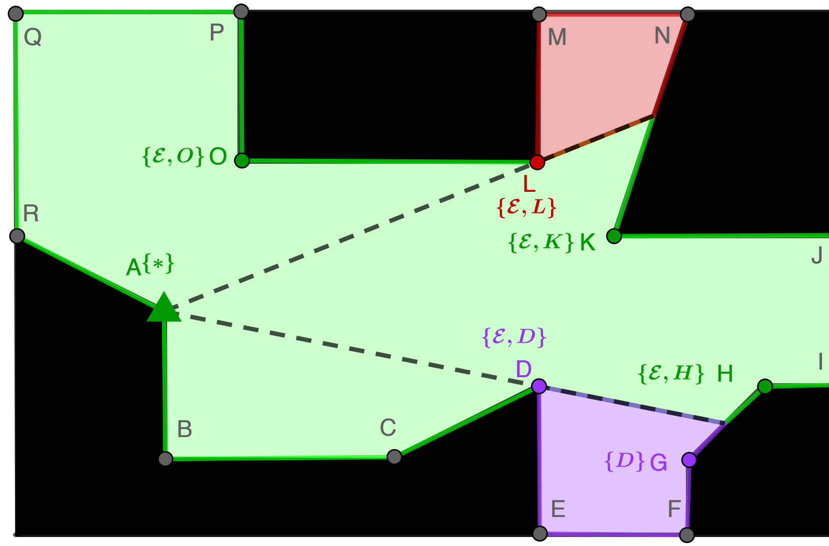

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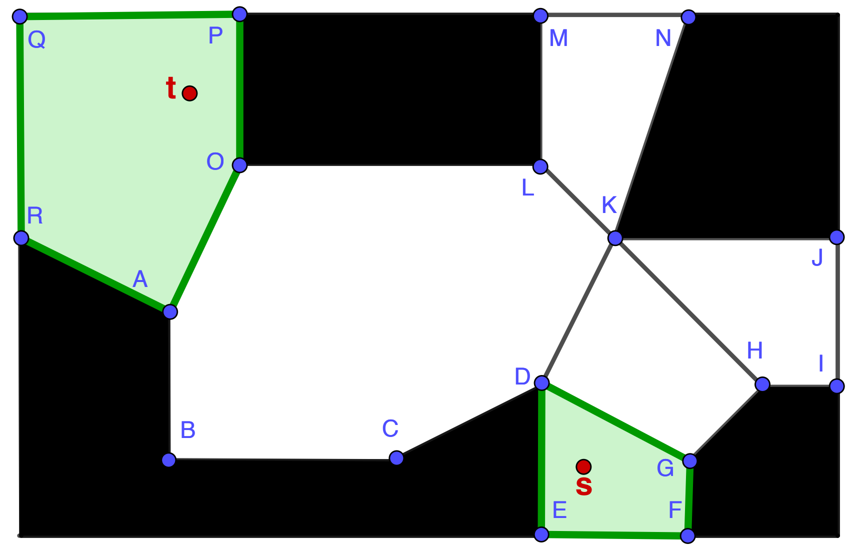
Our Approach
End Point Search (EPS)

- Euclidean-based CPD
- End Point Search (EPS)
  - Incremental Insertion
    - $Search_s$ & $Search_t$
    - V_s & V_t
    - Shortest Path (sp)



Shaded green area shows the space incrementally explored by $search_s$ and $search_t$

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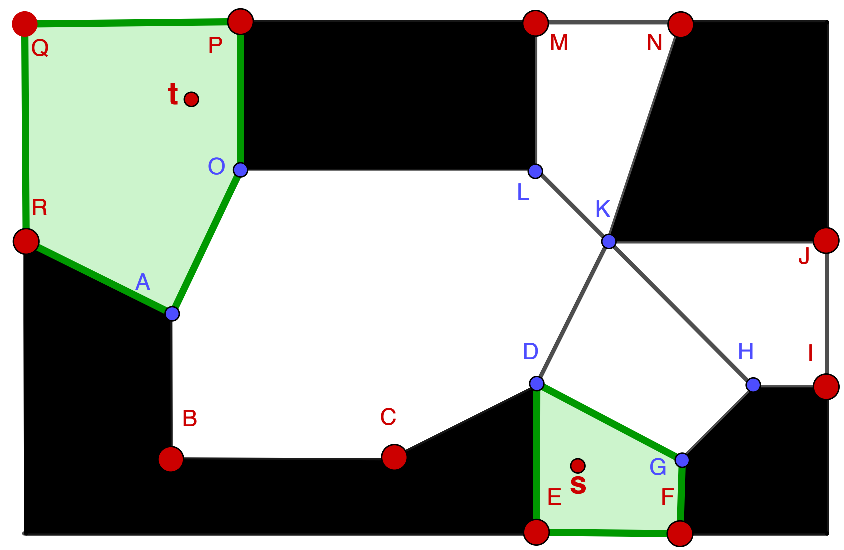
    - $Search_s$ & $Search_t$
    - V_s & V_t
    - Shortest Path (sp)
  - Vertex Pruning
    - Dead-end Vertices



Avoid accessing the non-convex visible vertices

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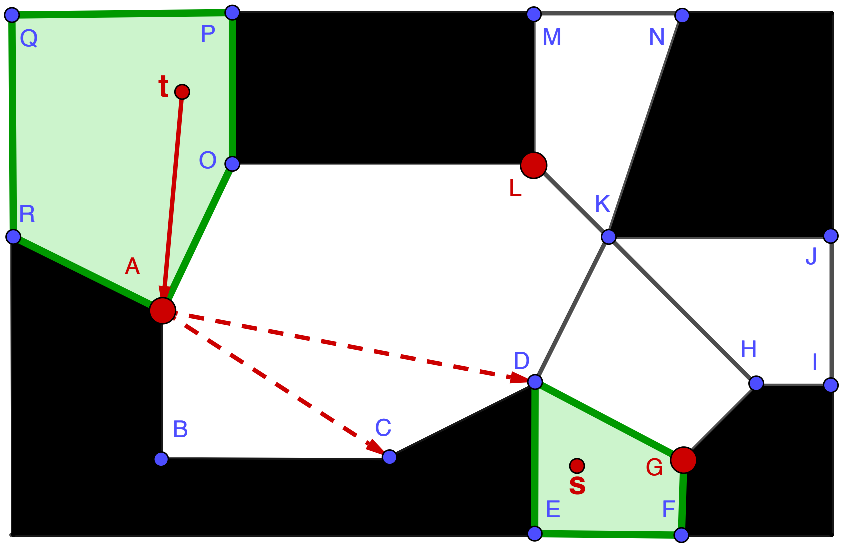
    - Non-turn Vertices



Avoid accessing the visible vertices can not possibly turn

End Point Search (EPS)

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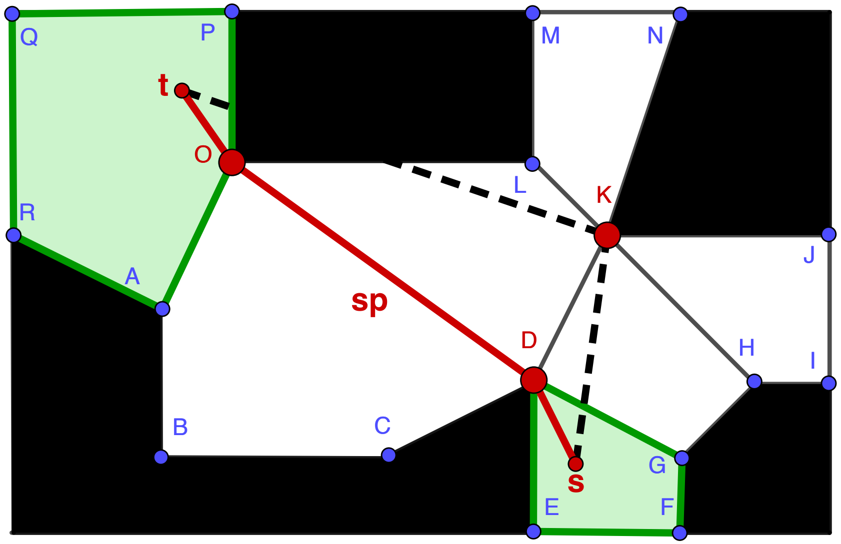
    - V_s & V_t
    - Shortest Path (sp)
  - Vertex Pruning
    - Dead-end Vertices
    - Non-turn Vertices
    - Distance Pruning

      d(s, K) + h (K, t) > |sp|



Avoid accessing the visible vertices that can be pruned based on the current solution

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    - V_s & V_t
    - Shortest Path (sp)
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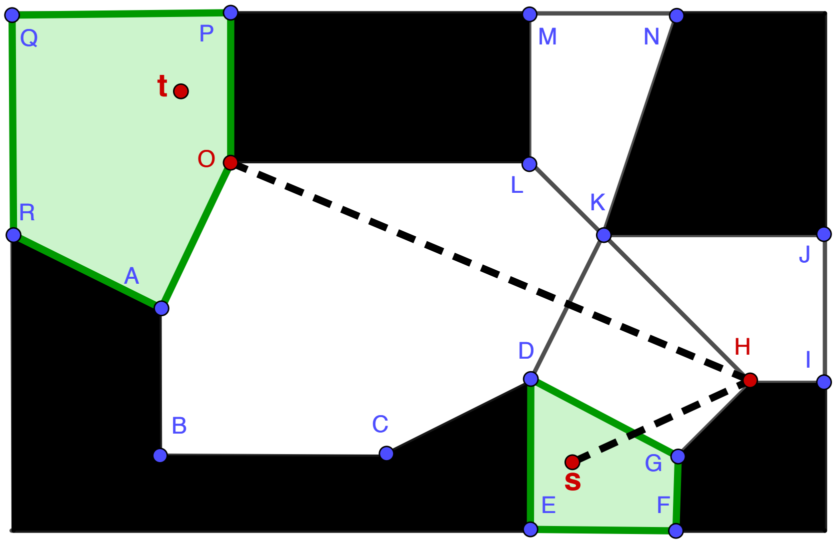
    - Dead-end Vertices
    - Non-turn Vertices
    - Distance-based Pruning
  - Path Pruning
    - Non-taut Paths

    i.e. (H,O): <s, H, O>



Stop path extraction when first move gives non-taut path

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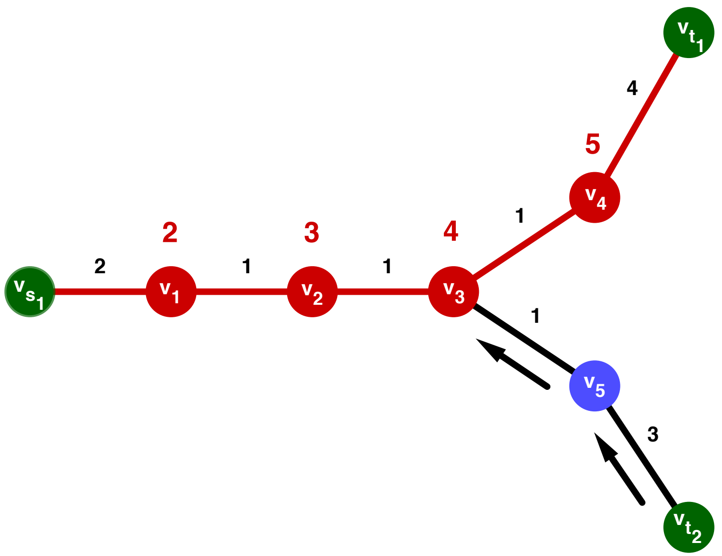
    - Non-taut Paths
    - Cost Caching



EPS cache distance on each node when extract paths from V_{t1} to V_{s1}. The path extraction from V_{t2} to V_{s1} terminate when reach a cached node (i.e. V_3)

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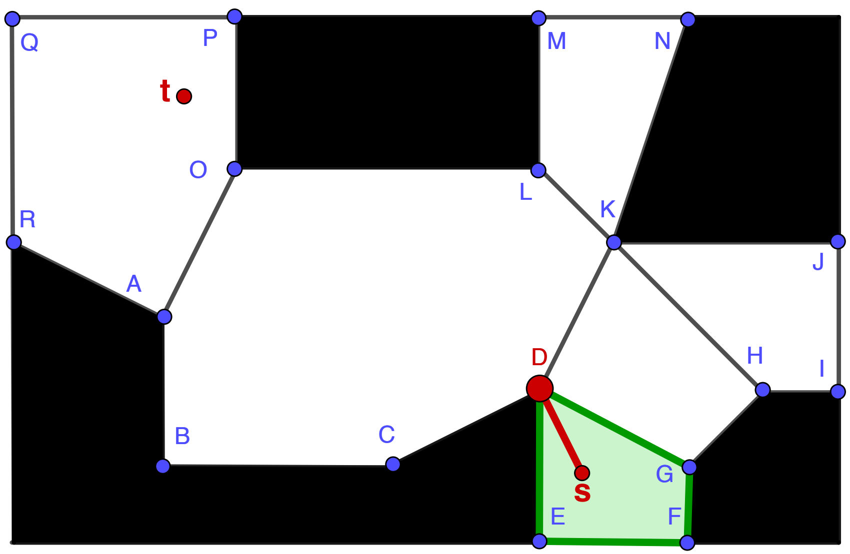
    - Cost Caching
  - Running Example



The shaded green area shows the space incrementally explored by $search_s$ and $search_t$

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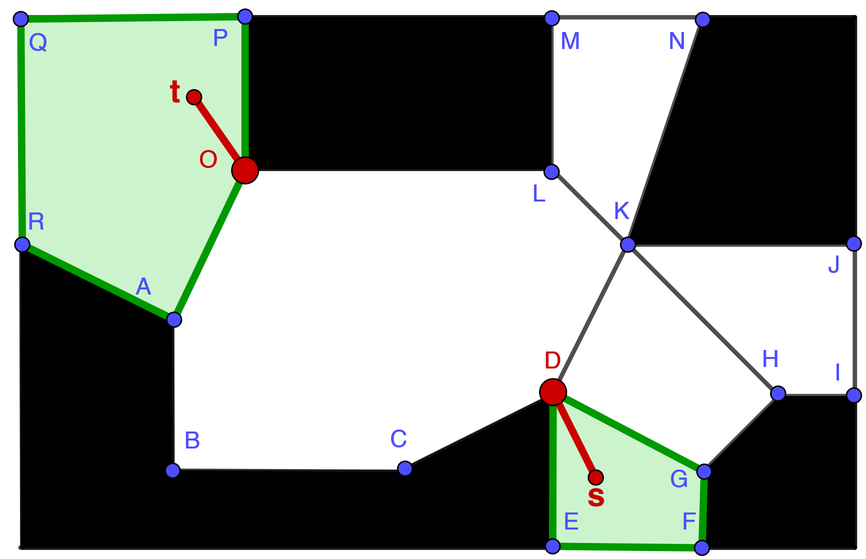

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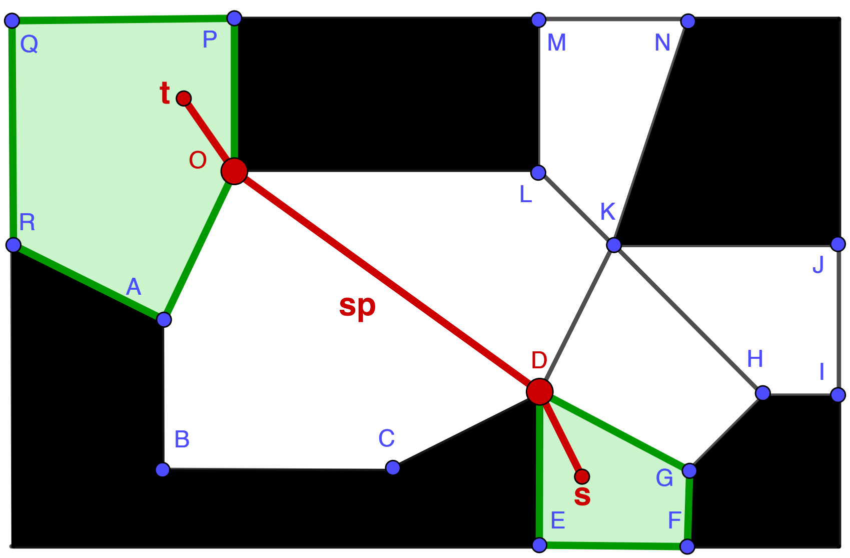

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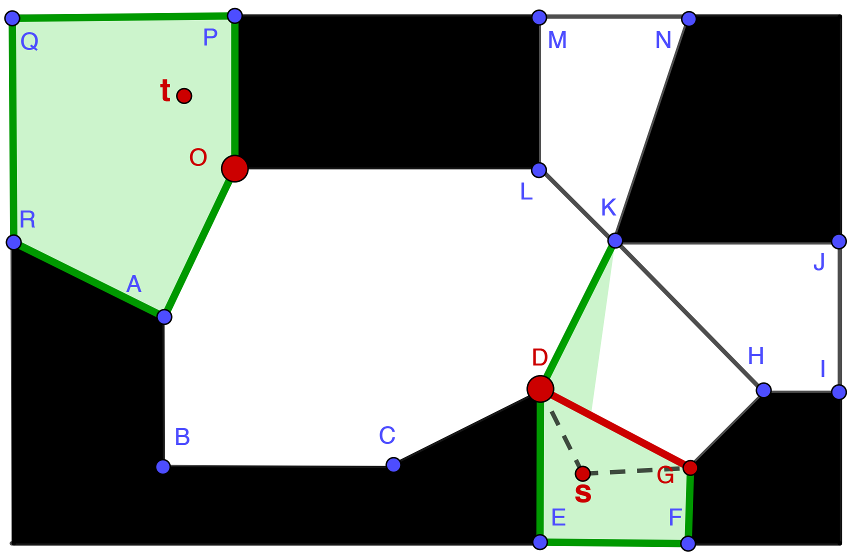
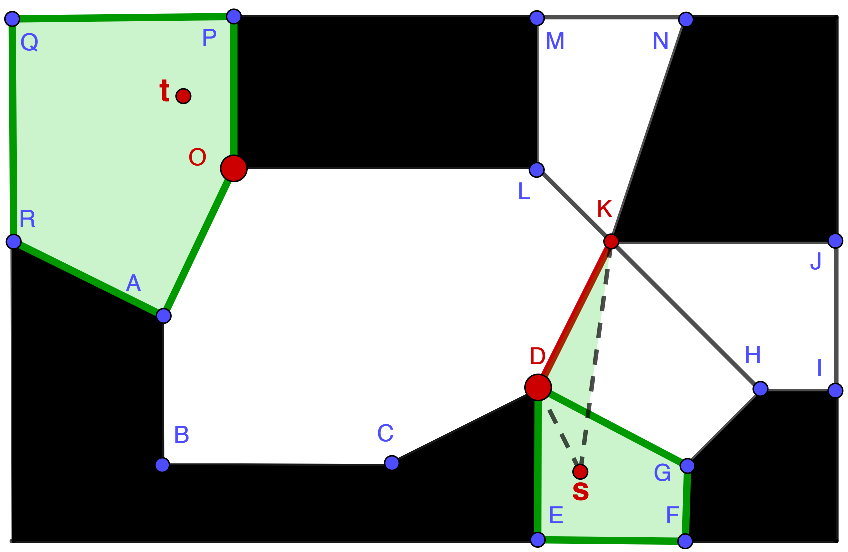
    - Cost Caching
  - Running Example



The shaded green areas show the space incrementally explored by $search_s$ and $search_t$

- Euclidean-based CPD
- End Point Search (EPS)
  - Incremental Insertion
    - $Search_s$ & $Search_t$
    - V_s & V_t
    - Shortest Path (sp)
  - Vertex Pruning
    - Dead-end Vertices
    - Non-turn Vertices
    - Distance-based Pruning
  - Path Pruning
    - Non-taut Paths
    - Cost Caching
  - Running Example



The shaded green areas show the space incrementally explored by $search_s$ and $search_t$

Our Approach
End Point Search (EPS)

- Euclidean-based CPD
- End Point Search (EPS)
  - Incremental Insertion
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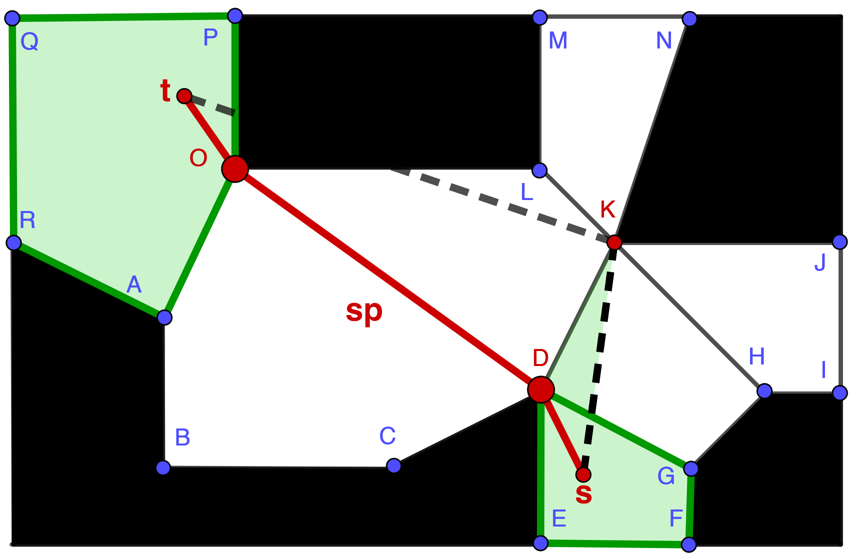

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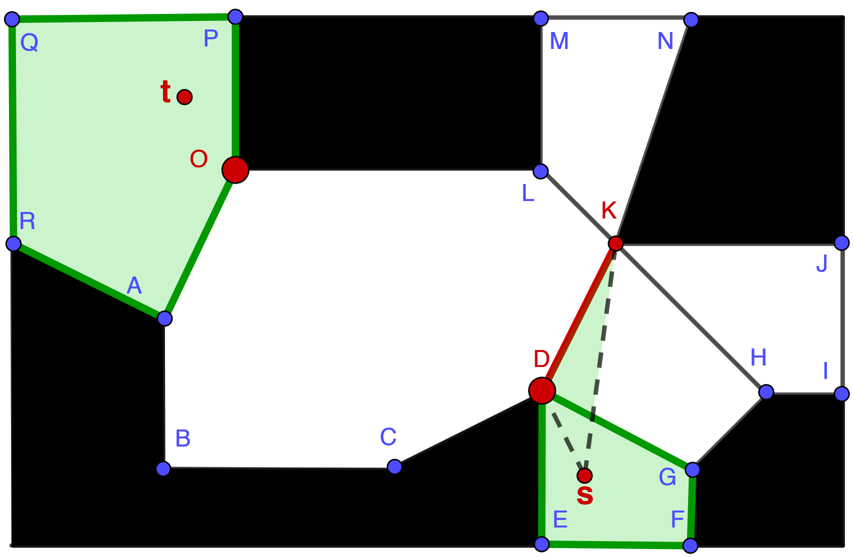

The shaded green areas show the space incrementally explored by $search_s$ and $search_t$

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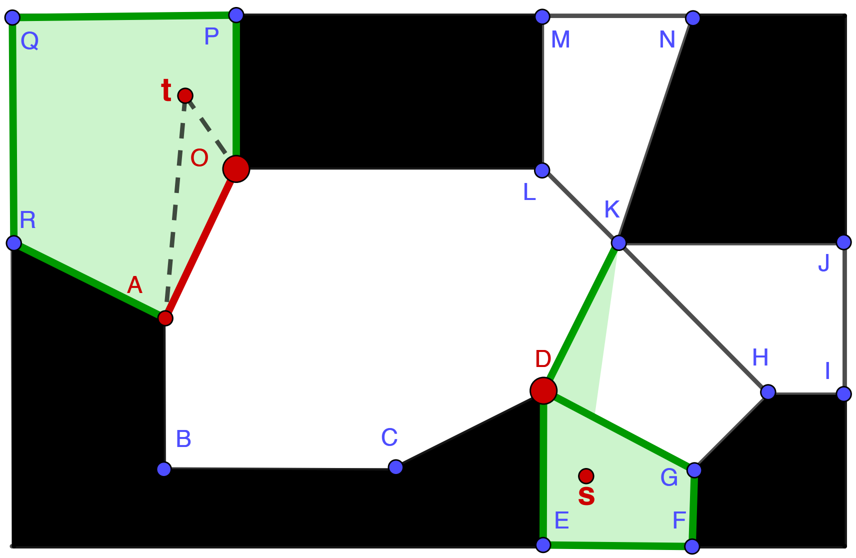

Shaded green areas show the space incrementally explored by $search_s$ and $search_t$

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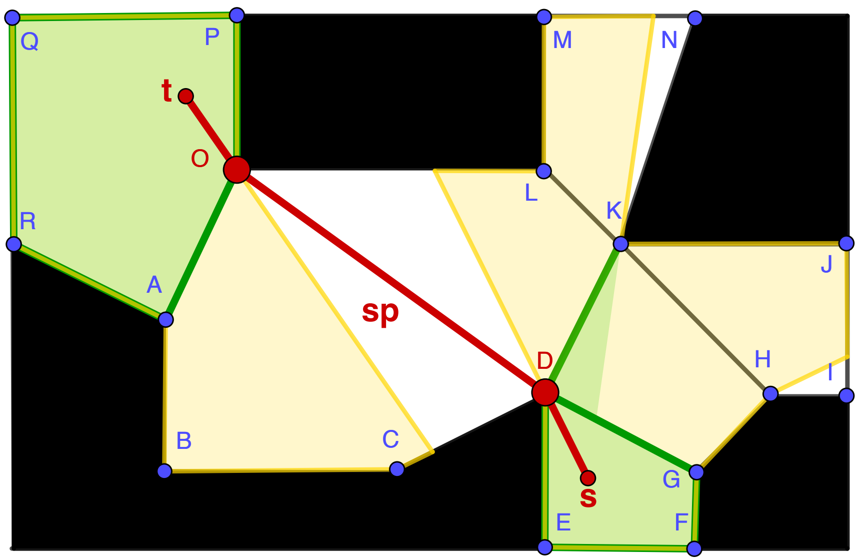
  - Running Example

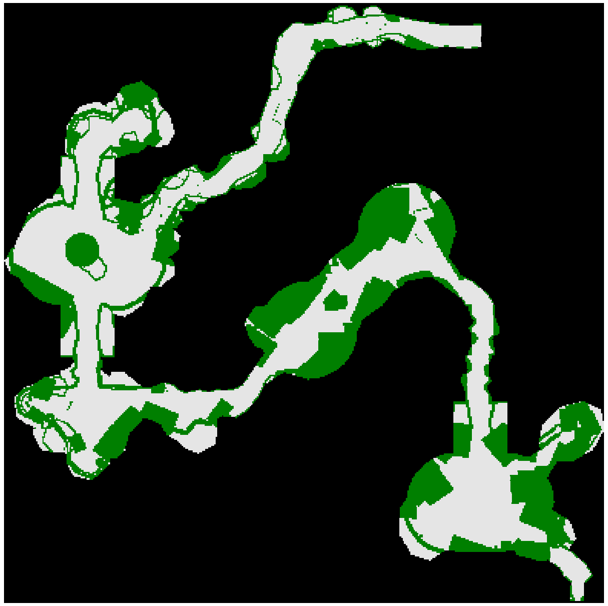


Shaded yellow areas correspond to the area visible from s and t. Shaded green areas show the space incrementally explored by Polyanya when $search_s$ and $search_t$ are both exhausted

Our Approach

Experimental Results

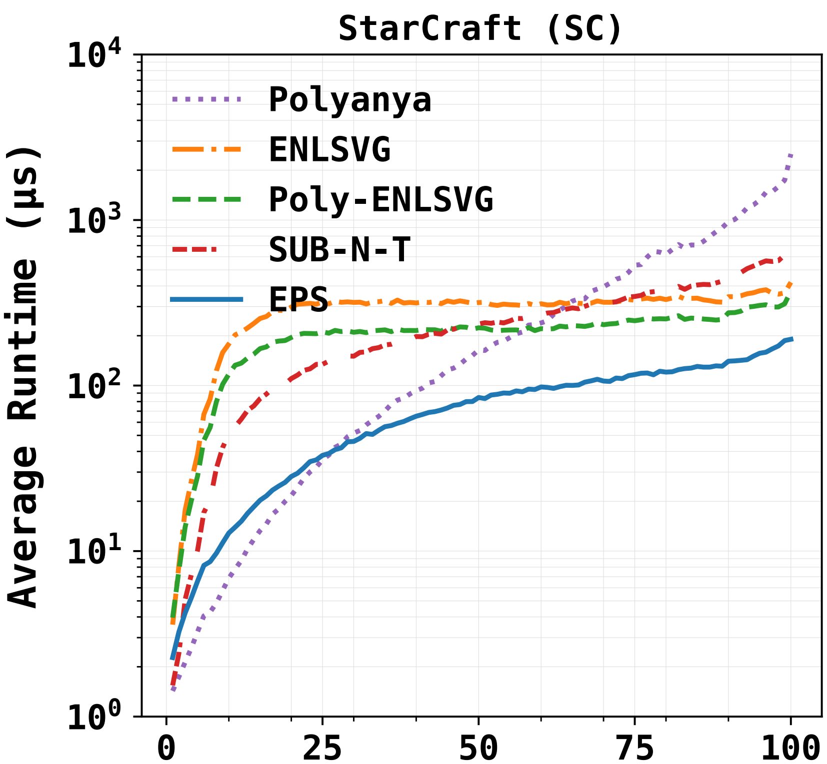
- Euclidean-based CPD
- End Point Search (EPS)
- Experimental Results
  - Benchmarks:
    - Game Maps from Sturtevant's Repository



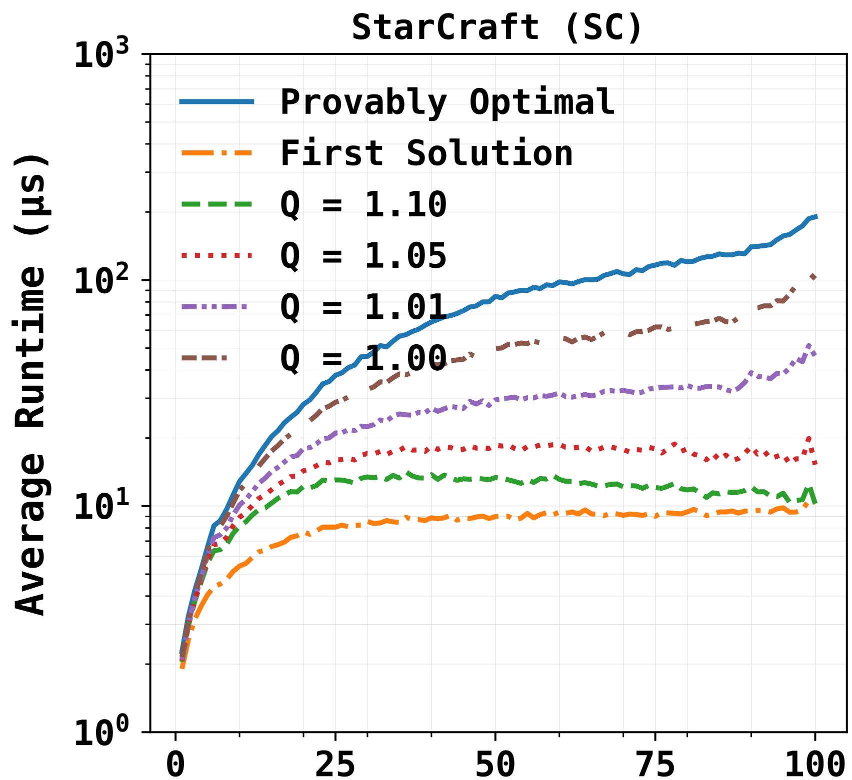
Euclidean-based CPD Statistics								
	#Map	#Queries	Build Time		Raw Memory		CPD Memory	
			Avg	Max	Avg	Max	Avg	Max
SC	75	198k	0.7	8	190	2202	2	14

Our Approach
Experimental Results

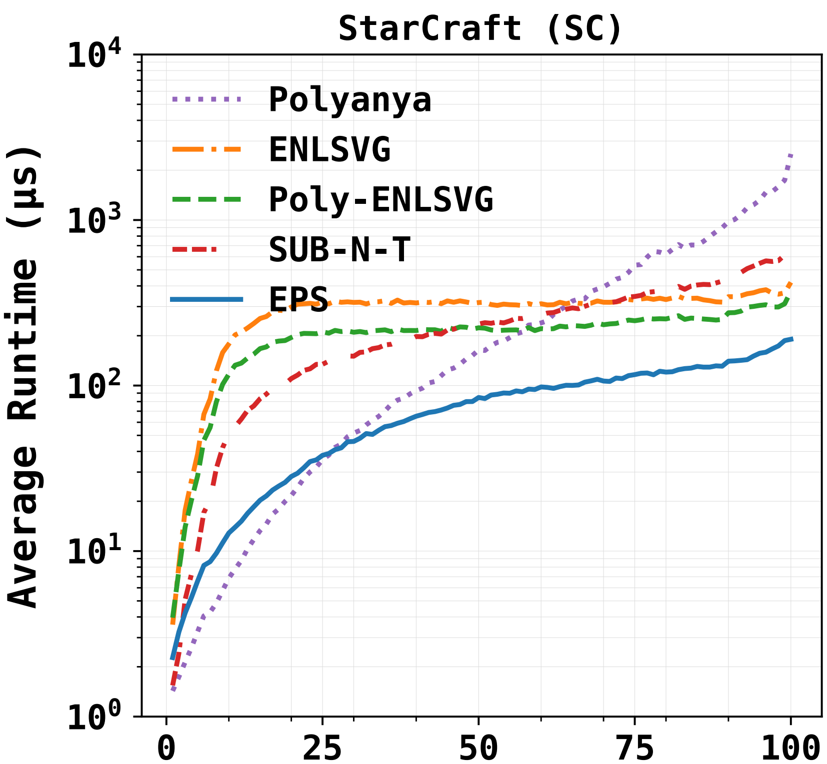
- Optimal Search



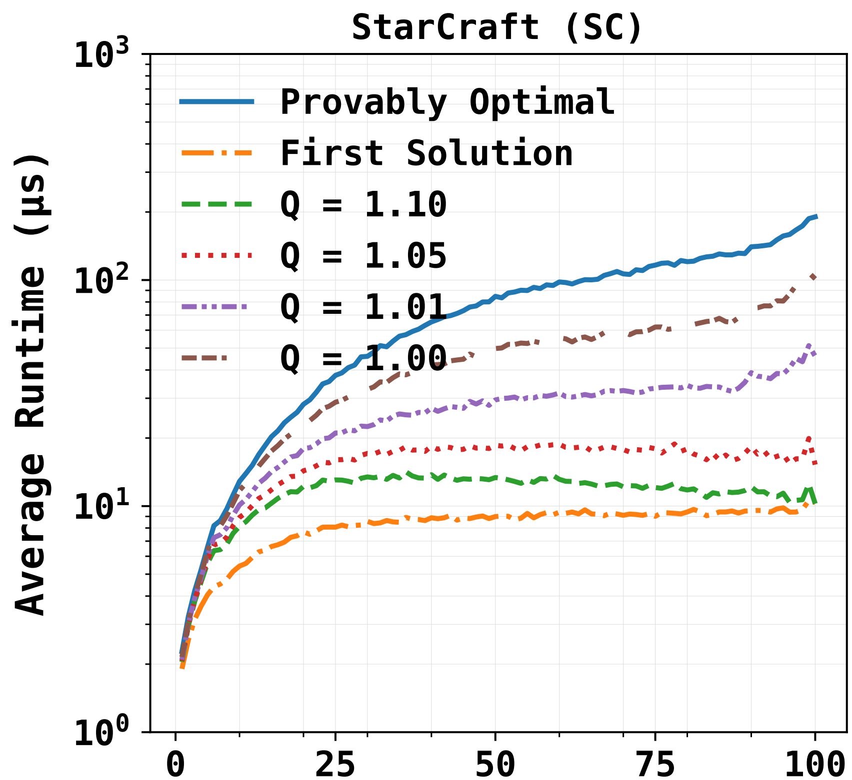
- Any-time Search



- Optimal Search



- Any-time Search



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Thank you for listening