Online Computation of Euclidean Shortest Paths in Two Dimensions

ICAPS 2020

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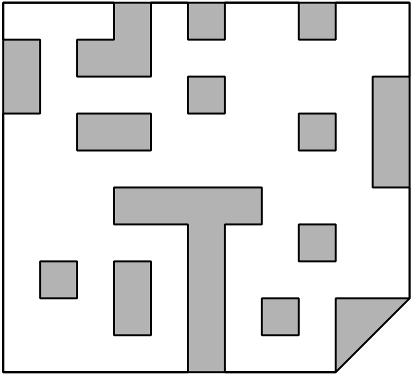
Monash University

Euclidean Shortest Path

- Pathfinding on the Euclidean plane



Euclidean Shortest Path

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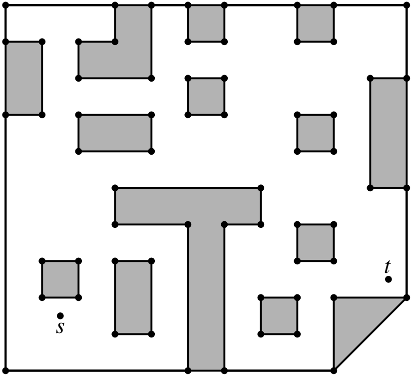

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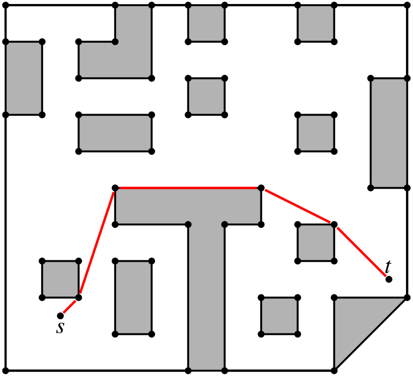

Euclidean Shortest Path

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- Takes as input start s, target t and a set of polygonal obstacles P
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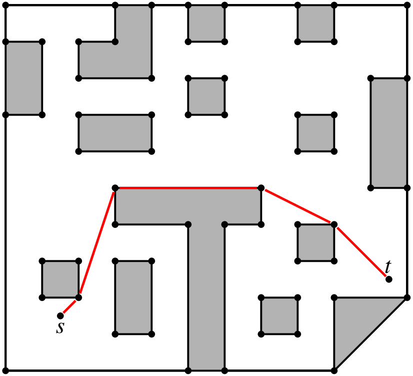
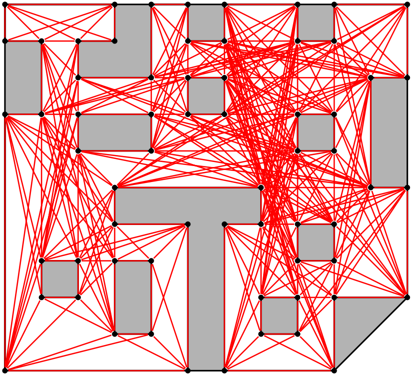
- Distance is based off the Euclidean distance $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$



Visibility Graph

- Visibility graphs can solve the Euclidean shortest path (Lozano-Pérez et al. 1979)



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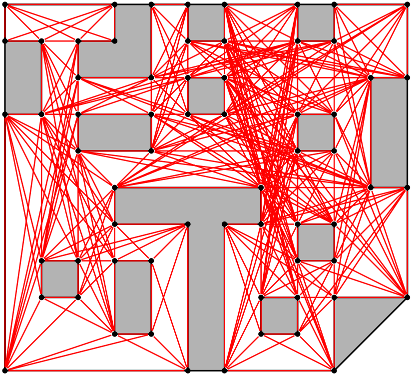

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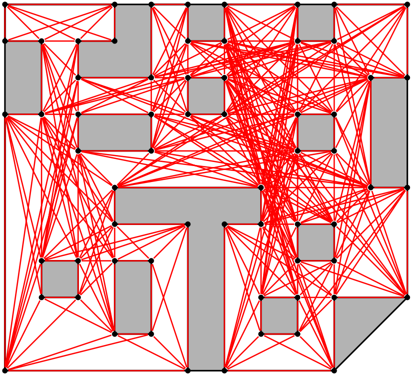
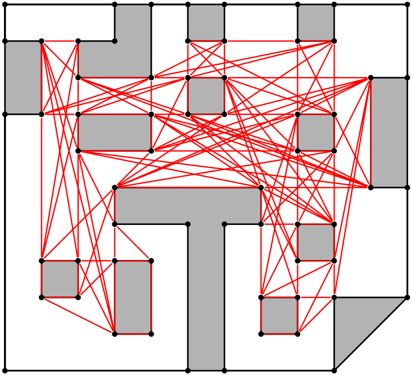
- A full visibility graph uses V^2 edges complexity



Sparse Visibility Graph

- A variant of the visibility graph (Oh et al., SoCS 2017)



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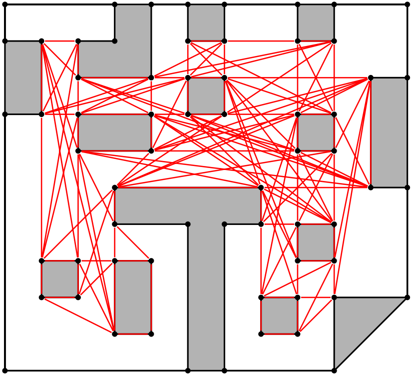
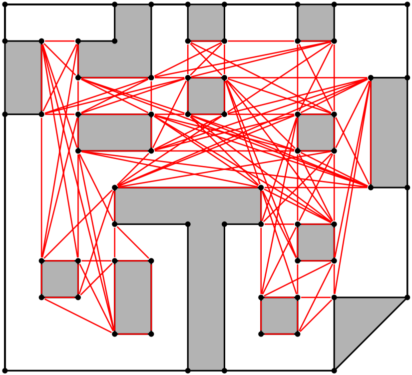


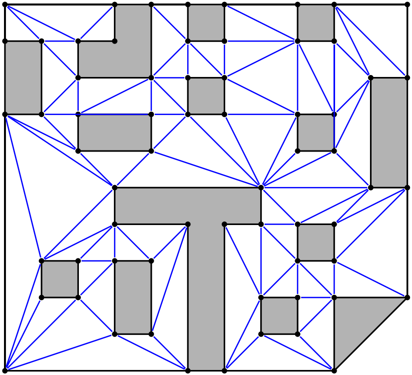
Sparse Visibility Graph

- A variant of the visibility graph (Oh et al., SoCS 2017)
- Keeps only edges that can form a shortest path
- Greatly reduces the density of edges



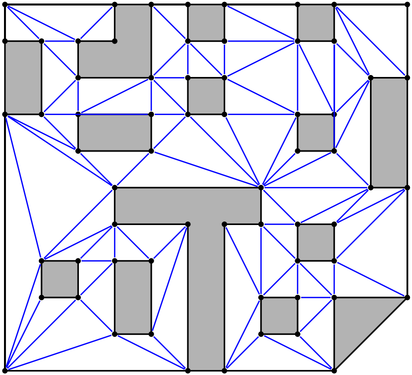
Navigation Mesh

- Inverts the search space from a set of non-traversable obstacles to traversable convex regions



Navigation Mesh

- Inverts the search space from a set of non-traversable obstacles to traversable convex regions
- Has a state-of-the-art solver Polyanya (Cui et al., IJCAI 2017)



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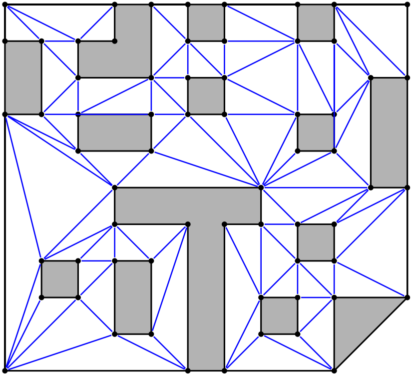
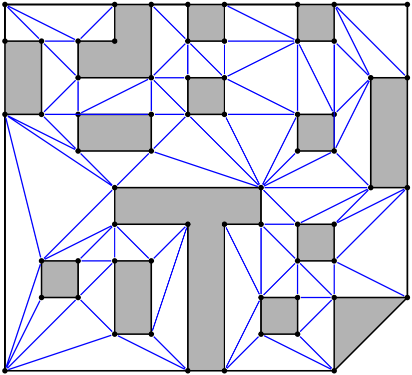


Navigation Mesh

- Inverts the search space from a set of non-traversable obstacles to traversable convex regions
- Has a state-of-the-art solver Polyanya (Cui et al., IJCAI 2017)
- Requires less memory and are easier to construct than visibility graphs
- Like visibility graphs, does not solve the problem directly



Introducing RayScan

- An online method for solving the Euclidean shortest path

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- Works as an on-the-fly partial visibility graph on a A* search

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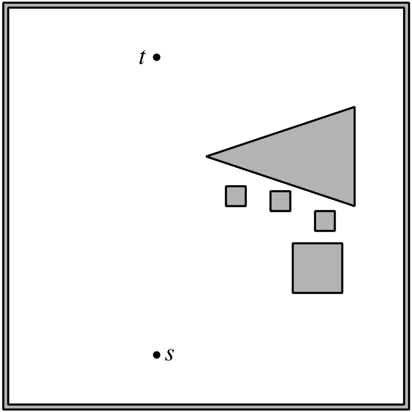
- An online method for solving the Euclidean shortest path
- Works as an on-the-fly partial visibility graph on a A* search
- Generates edges for each expanding node; they can be discarded after being pushed to the priority queue

RayScan Concepts

Shooting Rays Direct the Search

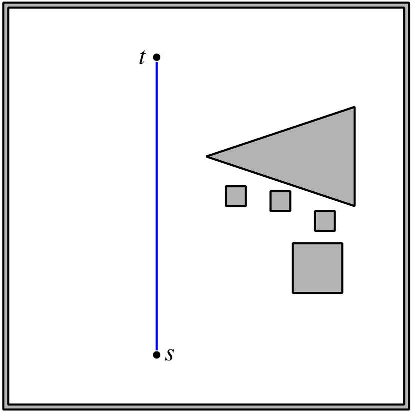
- Expand start node s



RayScan Concepts

Shooting Rays Direct the Search

- Expand start node s
- Shoot a ray towards target point t



RayScan Concepts

Shooting Rays Direct the Search

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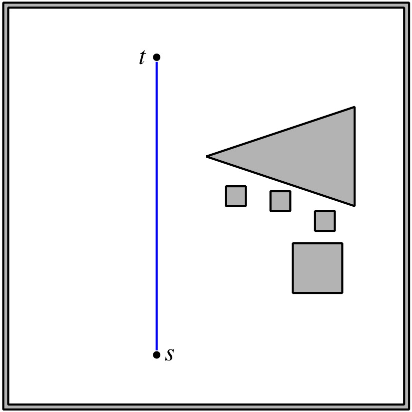
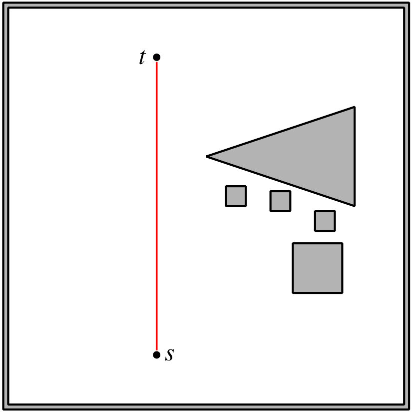
- If point is visible, it is a successor



RayScan Concepts

Shooting Rays Direct the Search

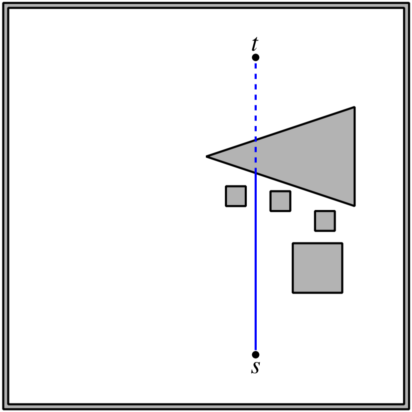
- Expand start node s
- Shoot a ray towards target point t
- If point is visible, it is a successor
- Direct line-of-sight from s to t is the simplest case



RayScan Concepts

Scanning

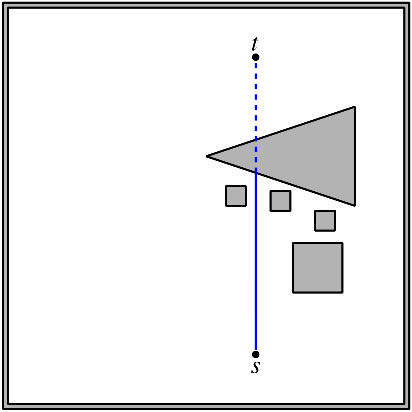
- Target t is not visible from start s



RayScan Concepts

Scanning

- Target t is not visible from start s
- First obstacle blocking target needs to be navigated around



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- Target t is not visible from start s
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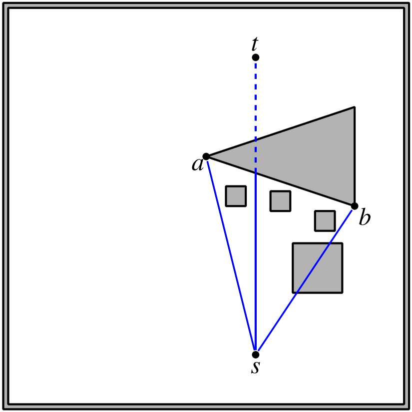
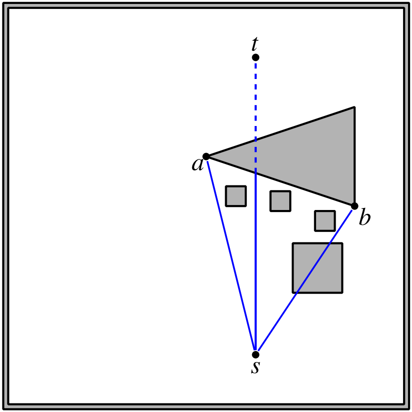
- Scanning is a core concept to find methods of navigating around obstruction



RayScan Concepts

Scanning

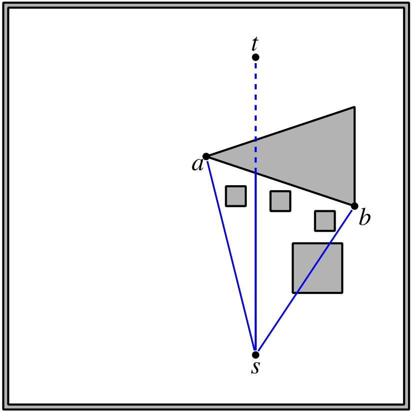
- Target t is not visible from start s
- First obstacle blocking target needs to be navigated around
- Scanning is a core concept to find methods of navigating around obstruction
- Find turning point a and b scanning CCW/CW that we can bend around



RayScan Concepts

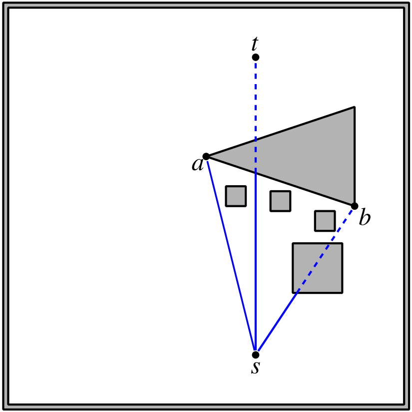
Recursion

- Turning point a is visible from s



RayScan Concepts
Recursion

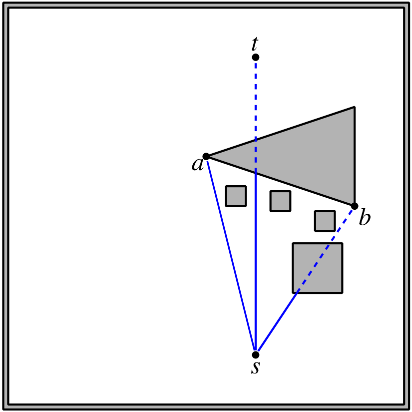
- Turning point *a* is visible from *s*
- Turning point *b* is blocked from *s*



RayScan Concepts

Recursion

- Turning point a is visible from s
- Turning point b is blocked from s
- The ray shot to b directs the search to find successors that may lead to it



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- Turning point *a* is visible from *s*
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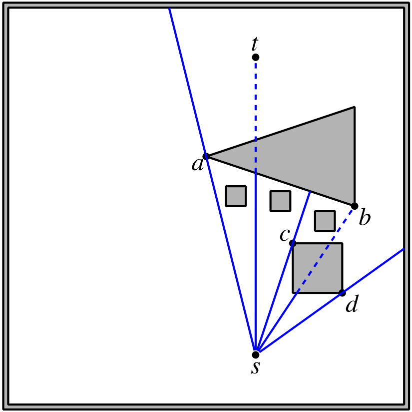
- Recurse the scan CCW/CW from obstruction intersection



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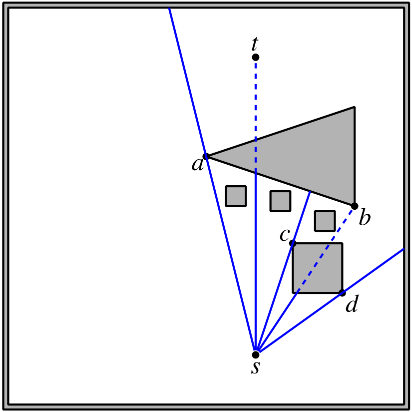
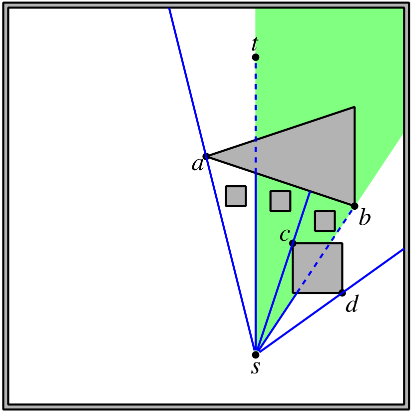
- Recurse the scan CCW/CW from obstruction intersection
- Successors *c* and *d* is found



RayScan Concepts

Angled Sectors

- Scan is restricted to a region called the angled sector



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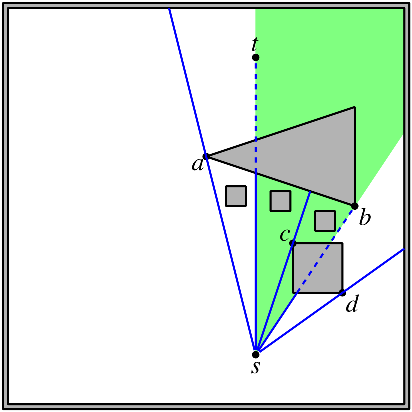
Angled Sectors

- Scan is restricted to a region called the angled sector
- Once the scan leaves the angled sector, it ends



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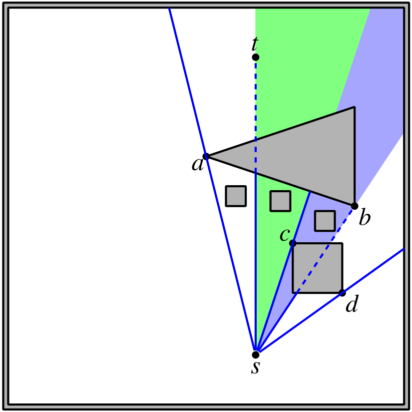

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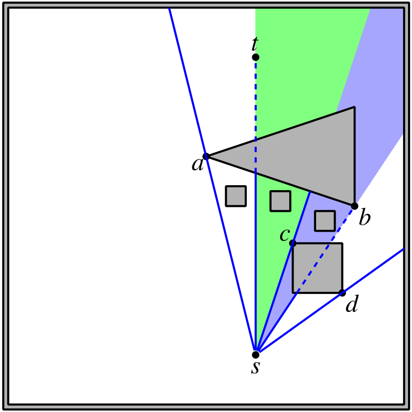

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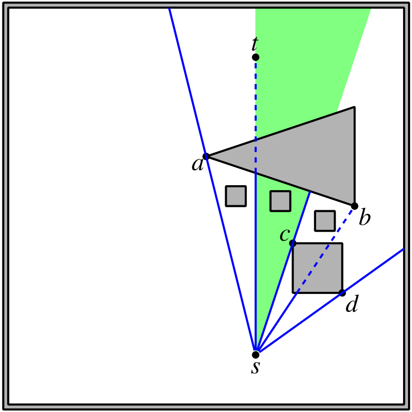
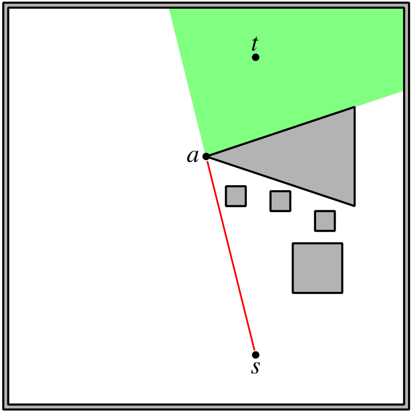
- After finding c, the angled sector gets splits
- The CCW scan uses the green split



RayScan Concepts

Next Expansion

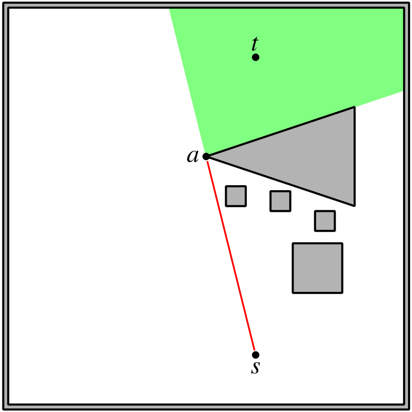
- A* search expands the smallest f-value a



RayScan Concepts

Next Expansion

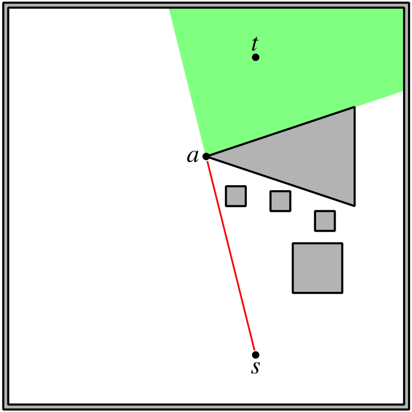
- A* search expands the smallest f-value a
- Each expanding node has a special angled sector known as the projection field



RayScan Concepts

Next Expansion

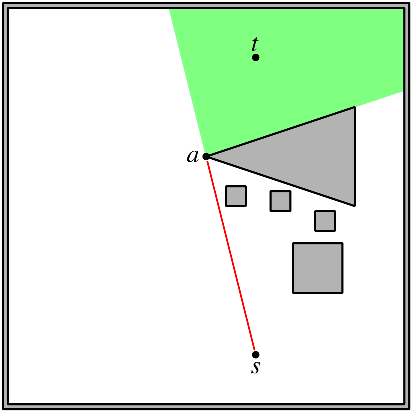
- A* search expands the smallest f-value a
- Each expanding node has a special angled sector known as the projection field
- All successor must fall within this field to ensure taut (bends around corner)



RayScan Concepts

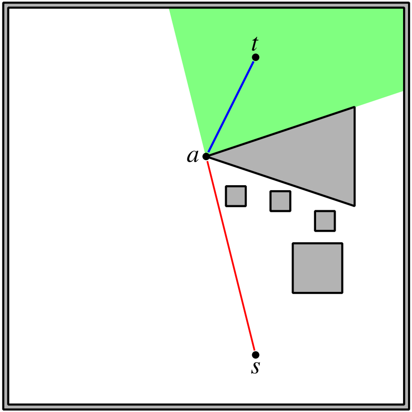
End Search

- Expanding a, target t is within the projection field



RayScan Concepts
End Search

- Expanding a, target t is within the projection field
- Shoot ray to t



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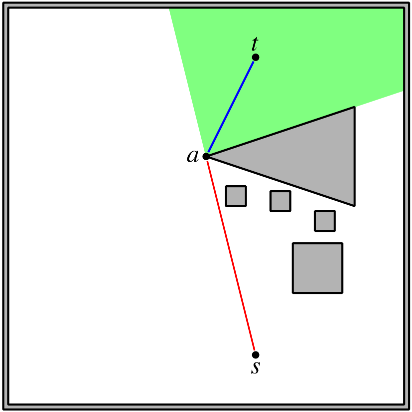
- Target is visible, successor is added



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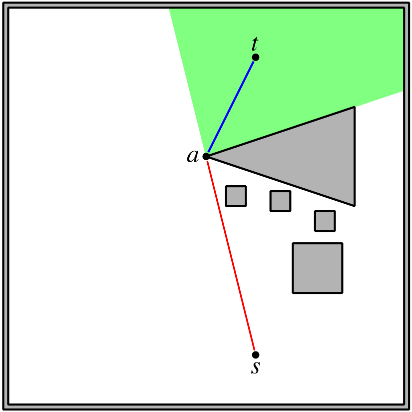

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End Search

- Expanding a, target t is within the projection field
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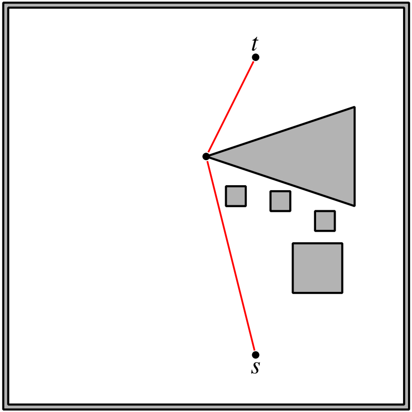
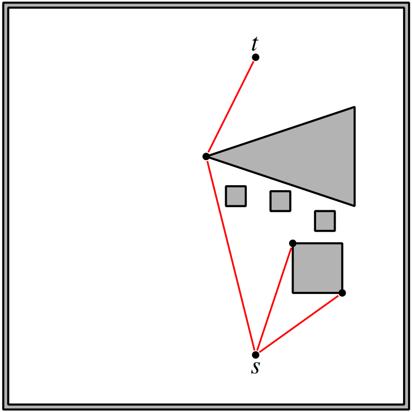
- If using a Euclidean heuristic value, search ends here



RayScan Concepts

Skipped Successors

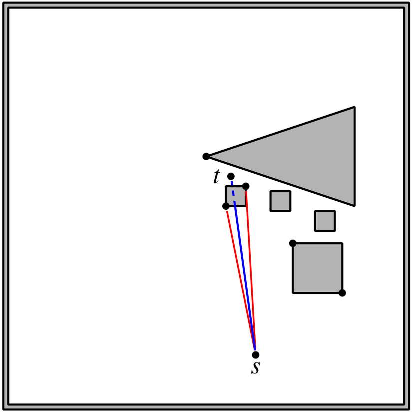
- Multiple squares are not considered



RaySan Concepts

Skipped Successors

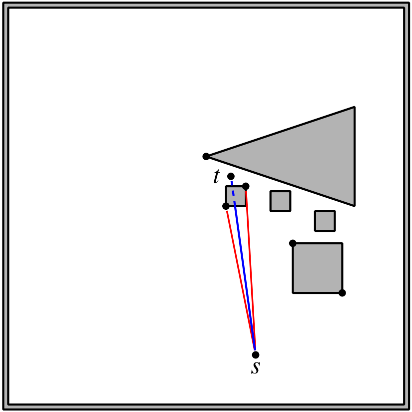
- Multiple squares are not considered
- Moving target t behind a square makes it relevant



RayScan Concepts

Skipped Successors

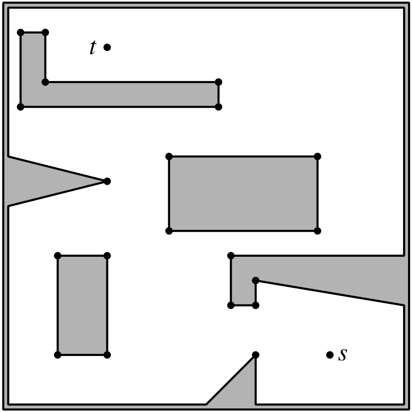
- Multiple squares are not considered
- Moving target t behind a square makes it relevant
- Since rays direct the search, this reduces the successors and number of rays shot



Comparisions to Visibility Graphs

RayScan

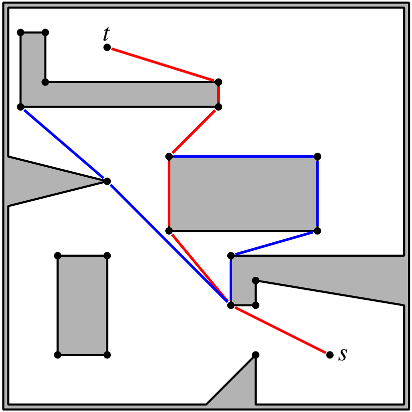
- Applying RayScan to a larger scenario



Comparisions to Visibility Graphs

RayScan

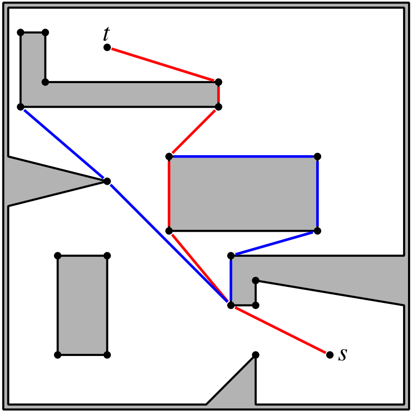
- Applying RayScan to a larger scenario
- Diagram shows RayScan search successors



Comparisions to Visibility Graphs

RayScan

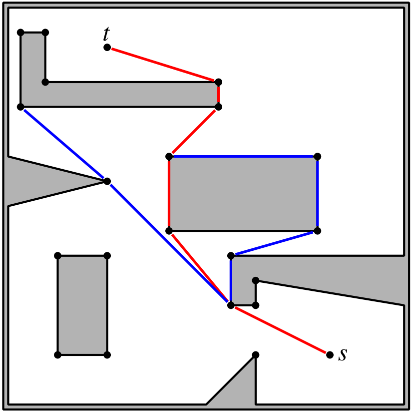
- Applying RayScan to a larger scenario
- Diagram shows RayScan search successors
- Red line is the shortest path



Comparisions to Visibility Graphs

RayScan

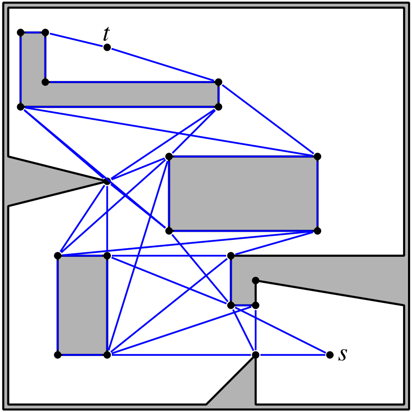
- Applying RayScan to a larger scenario
- Diagram shows RayScan search successors
- Red line is the shortest path
- Blue lines are other successors found during the search



Comparisions to Visibility Graphs

Sparse Visibility Graph

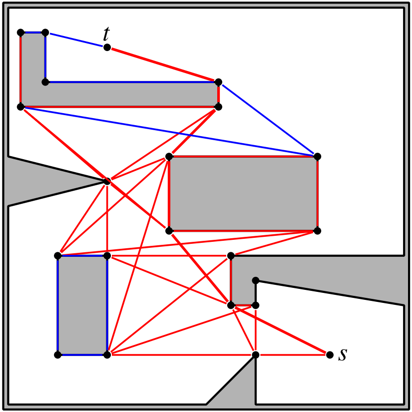
- Blue lines show the edges of the sparse visibility graph



Comparisions to Visibility Graphs

Sparse Visibility Graph

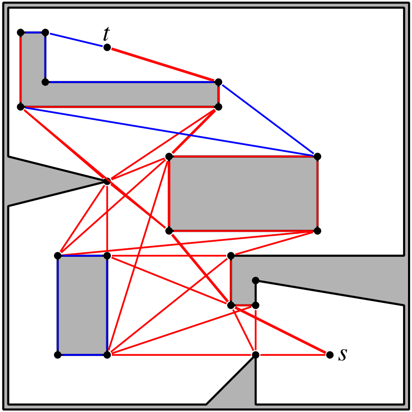
- Blue lines show the edges of the sparse visibility graph
- Red lines show the edges expanded during an A* search



Comparisions to Visibility Graphs

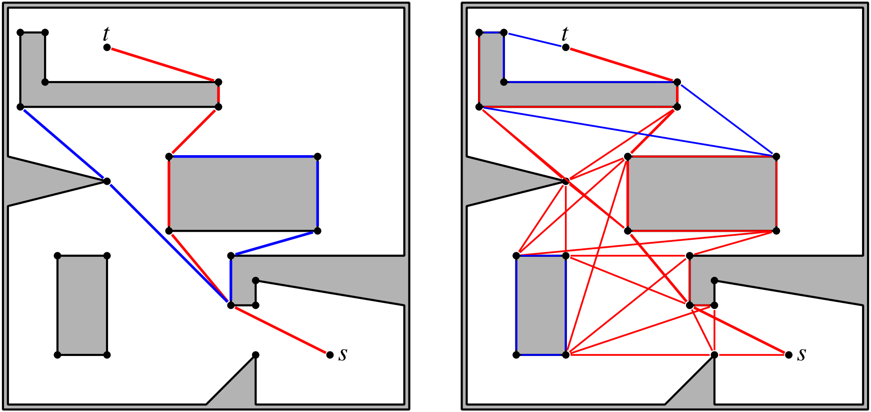
Sparse Visibility Graph

- Blue lines show the edges of the sparse visibility graph
- Red lines show the edges expanded during an A* search
- RayScan generates edges found on the sparse visibility graphs on-the-fly



Comparisions to Visibility Graphs

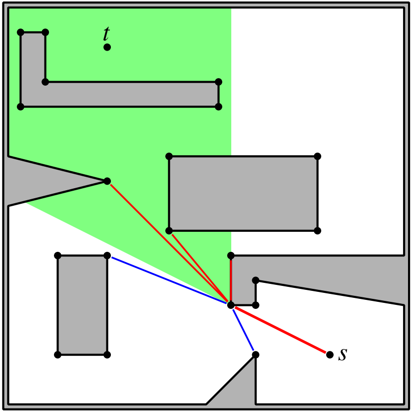
Sparse Visibility Graph Compare



Comparisions to Visibility Graphs

Visibility Graph with Projection Field

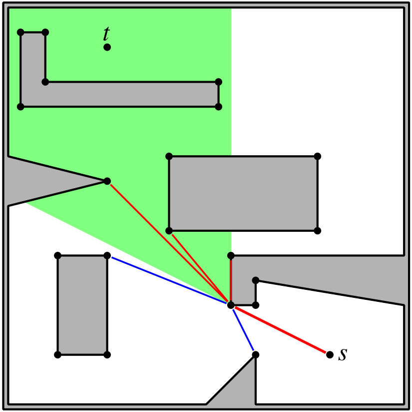
- The projection field concept can be applied to visibility graph on A*



Comparisions to Visibility Graphs

Visibility Graph with Projection Field

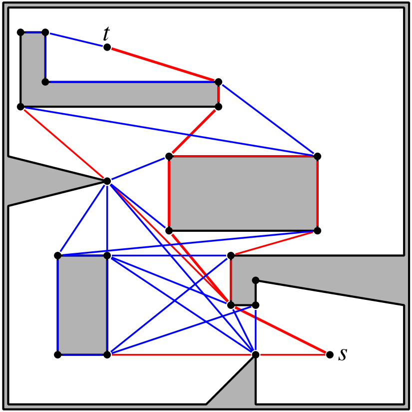
- The projection field concept can be applied to visibility graph on A*
- Add only the successors of A* within the projection field



Comparisions to Visibility Graphs

Visibility Graph with Projection Field

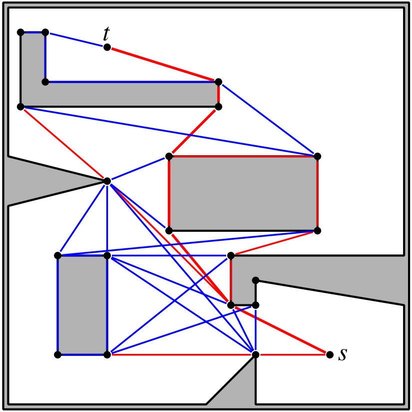
- The projection field concept can be applied to visibility graph on A*
- Add only the successors of A* within the projection field
- The search proceeds similarly to RayScan with this change



Comparisions to Visibility Graphs

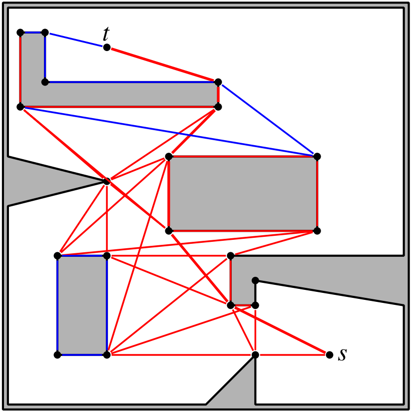
Visibility Graph with Projection Field

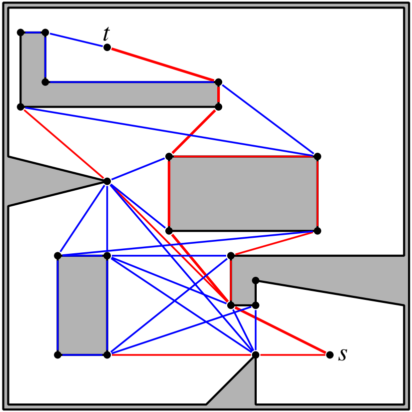
- The projection field concept can be applied to visibility graph on A*
- Add only the successors of A* within the projection field
- The search proceeds similarly to RayScan with this change
- This is referred as taut A* by Oh et al. (2017)



Comparisions to Visibility Graphs

Visibility Graph with Projection Field Compare





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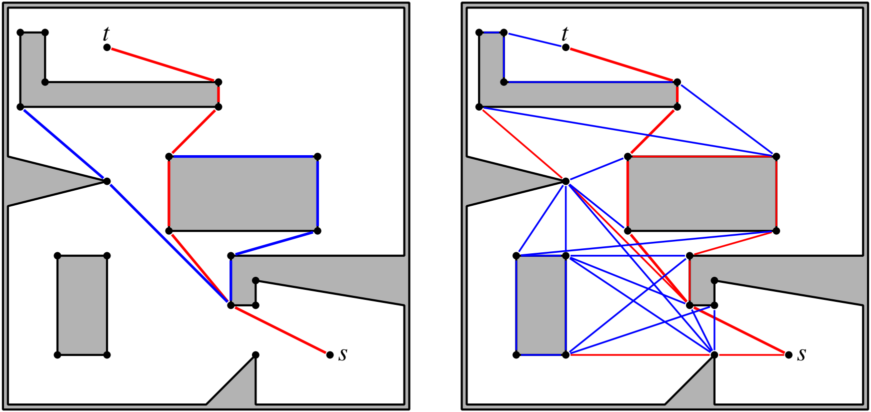
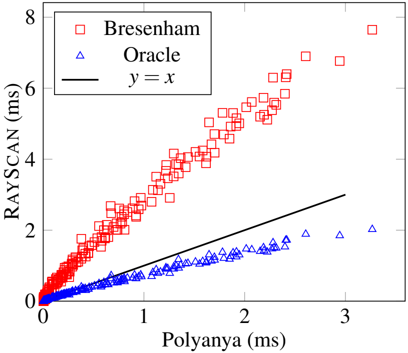


Results Presented in Paper

- Testing against Moving AI Lab pathfinding benchmarks (Sturtevant 2012)

Starcraft Aurora Map



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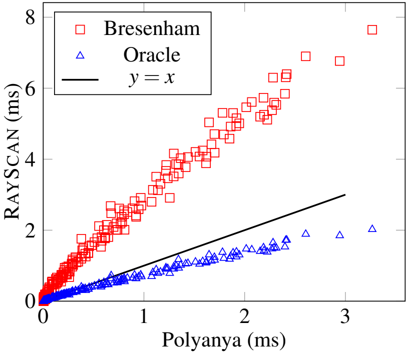

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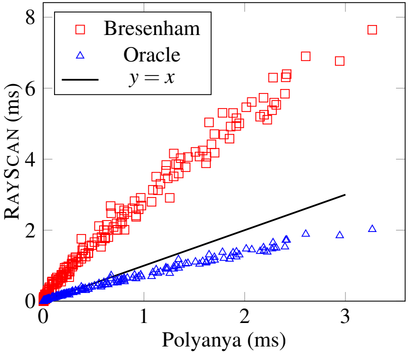

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- Testing against Moving AI Lab pathfinding benchmarks (Sturtevant 2012)
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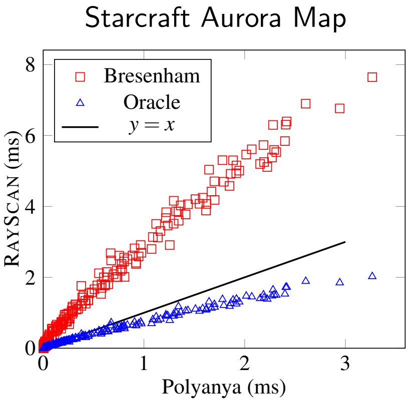
- Bresenham is RayScan using a Bresenham line for the ray shooting (Bresenham 1965)
- Oracle uses a free ray shooter



Recap

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- RayScan works directly on the environment
- Well suited to single instance or dynamically changing maps
- Performance dependent on ray shooter (i.e. more than half runtime is shooting rays)

References

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