Towards Autonomous Topological Place Detection Using the Extended Voronoi Graph

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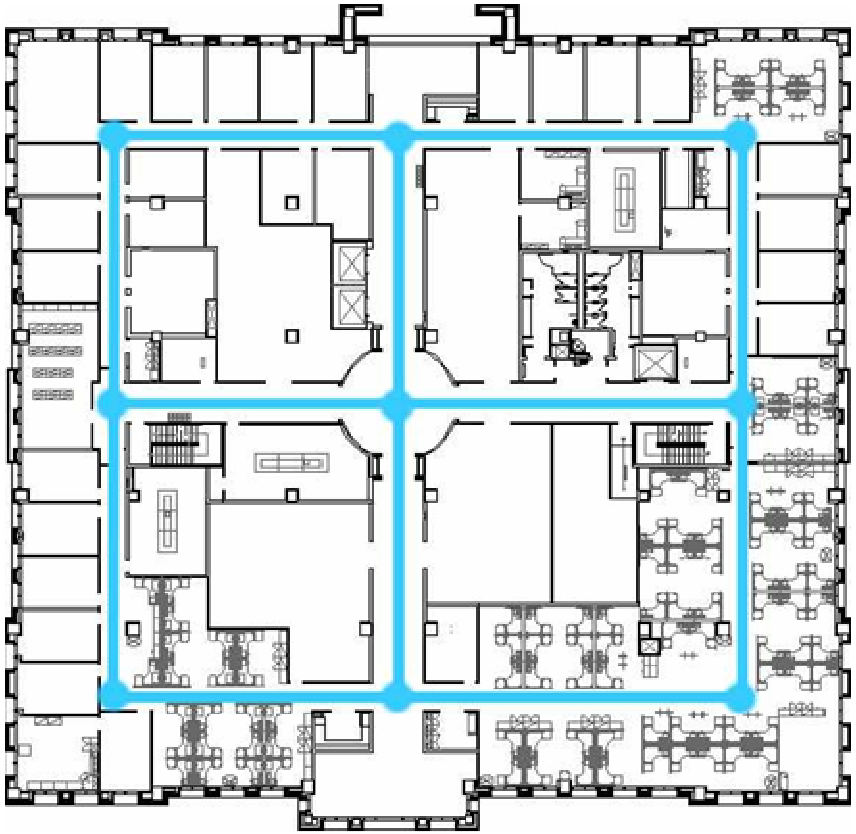
Problem Assumptions

- This work focuses on dead-ends, intersections, and doorways.
  - Smallest, atomic places sufficient for topological modeling.
  - Psychologically motivated

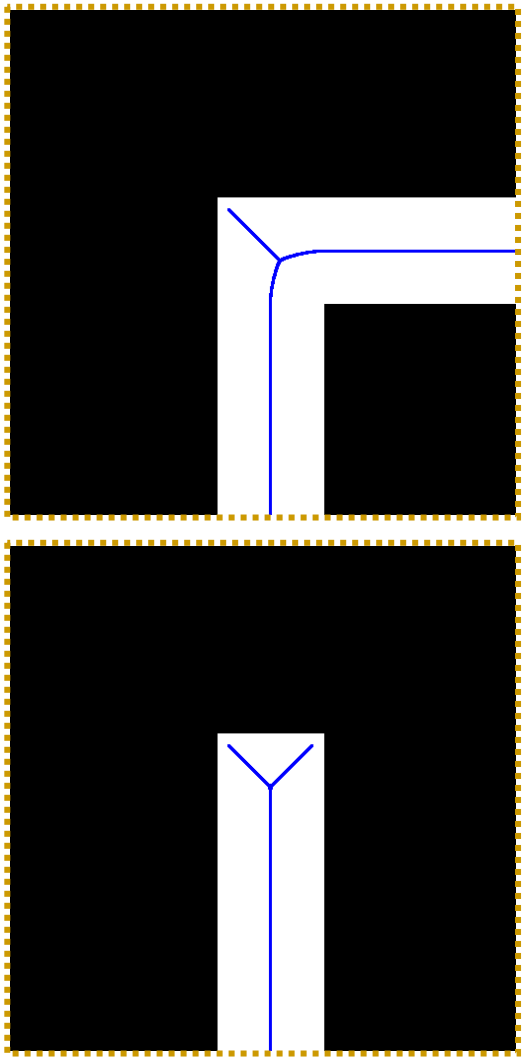


Previous Solutions

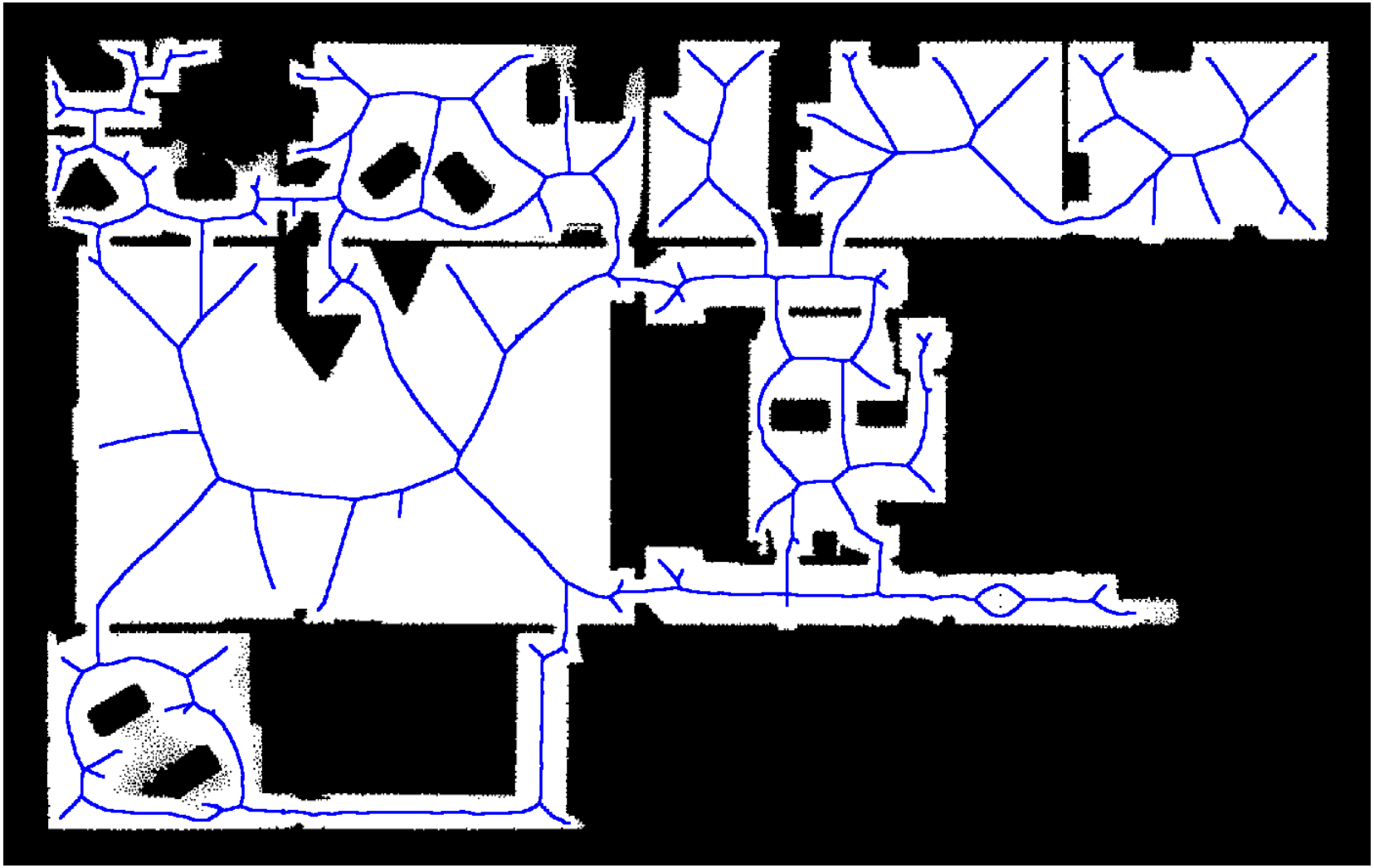
- Ad-hoc detection of simple intersections
  - Hand-coded
  - Environment dependent
  - Brittle
- Voronoi graph defines paths
  - Principled approach
    - Well-defined in enclosed environments
    - Work even in unconventional / non-perpendicular intersections
  - Experimentally validated in a number of environments
  - Choset and Nagatani, Trans. Robotics & Automation, 2001

Places at Voronoi Graph Junctions

- Voronoi graph – 1D set of points equidistant to the N (or more) closest obstacles in N dimensions.
- Usually:
  - Wheeled mobile robots
  - Planar range-sensors
  - 2D occupancy grid
- Places – branching points in the Voronoi graph
  - junctions



Voronoi Graph of a Global Metrical Map



Voronoi Problems

- Detecting Voronoi junctions has demonstrated some success for autonomous place detection.
- However, there are well known problems:
  - Unreliable
    - Spurious detections
    - Missed detections
    - Multiple places in complex intersections
  - Environment dependent
    - Only works in “enclosed” regions (at least N nearby obstacles)

Our Contributions

1. Provide a principled approach to pruning the Voronoi graph.
   - Reduces spurious Voronoi branches (i.e. paths)

2. Provide a simple extension to the standard Voronoi graph definition.
   - Allows non-enclosed (e.g. outdoor) environments

3. Provide a definition of intersections that is better than Voronoi junctions.
   - Reduces missed places
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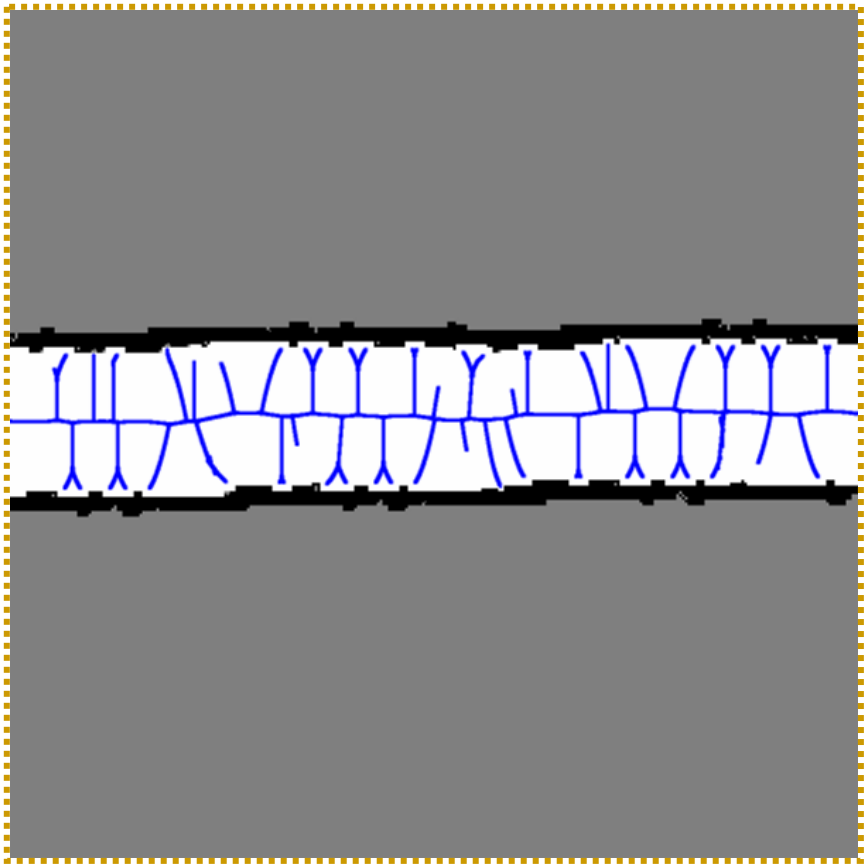
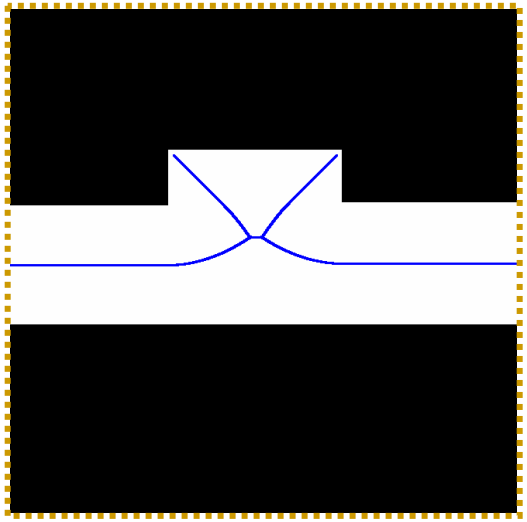
Pruning the Voronoi Graph

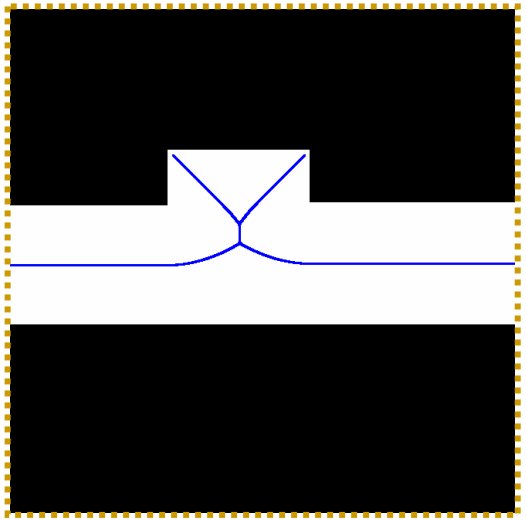
- Pruning is necessary to remove spurious branches.
- Choset's method
  - Remove terminal branches that only touch 2 obstacles.

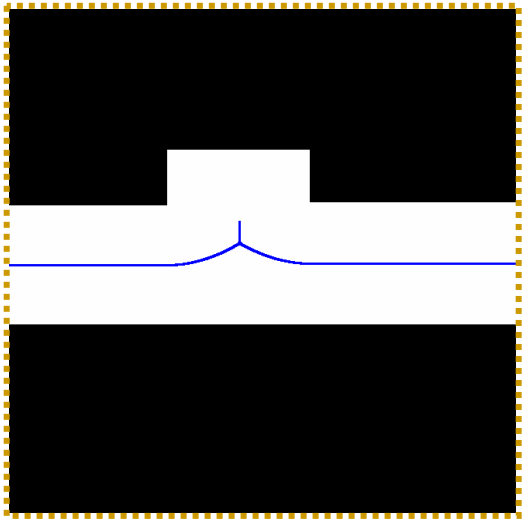


Pruning Failures

- Fixed-depth pruning fails for hierarchical branching.

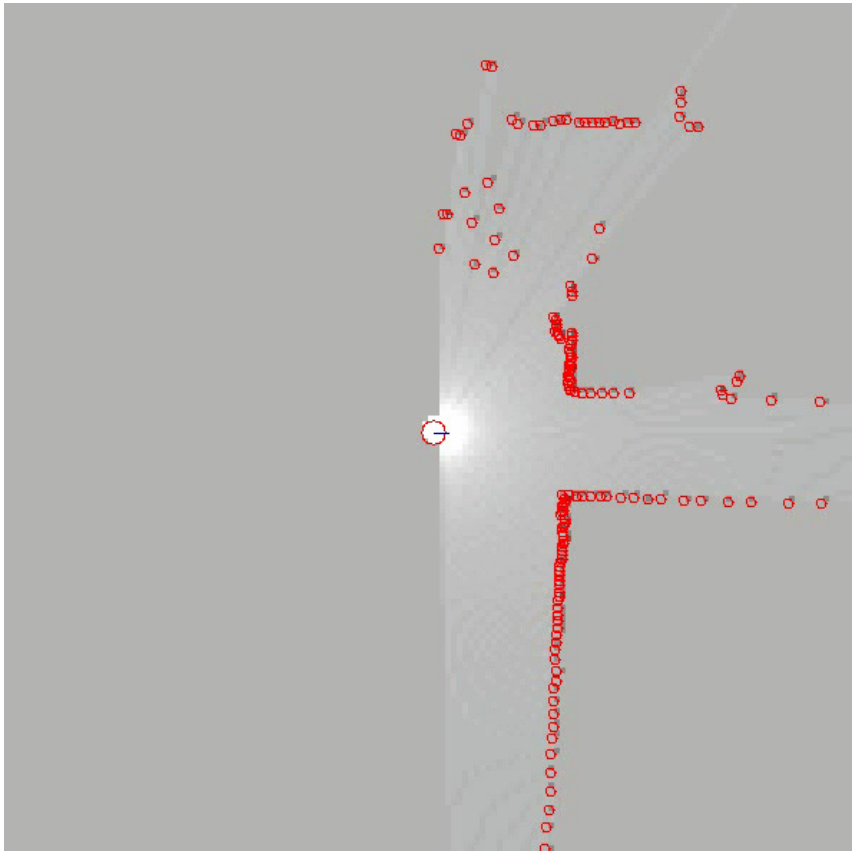






Our Solution to Pruning (Background)

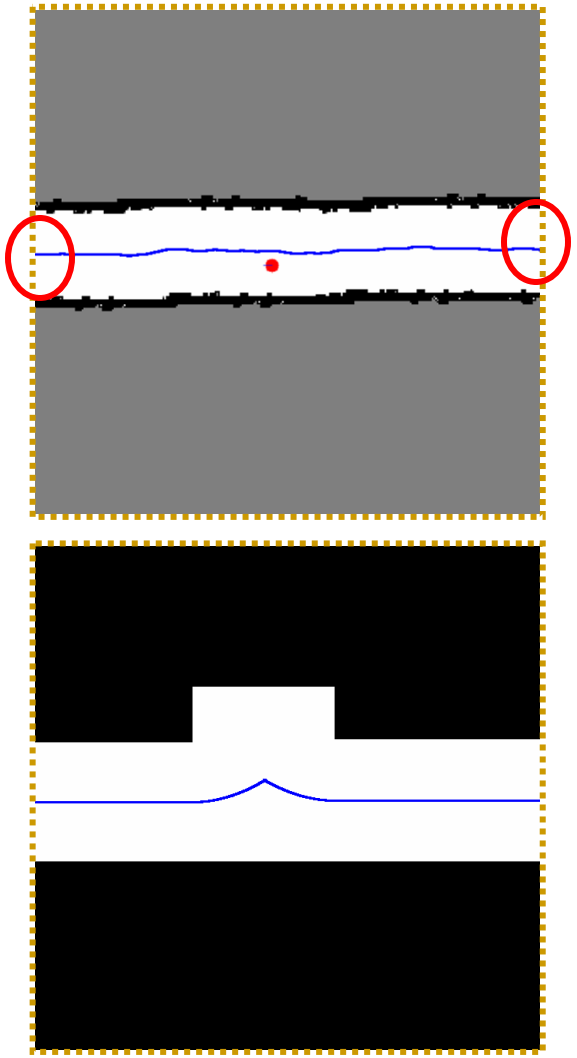
- There is always a fixed size, scrolling occupancy grid centered near the robot.
- (From previous work)
  - Small-scale space – local metrical model
  - Large-scale space – global topological model
  - If desired – global metrical model built using the topological skeleton



Video

Our Solution to Pruning

- Define exits as points in the Voronoi graph that:
  - touch the grid edge
  - touch “unknown” space (gray cells) in the grid
- Find the minimum spanning tree that connects the exits.
  - Dead-ends are a simple special case.
- The size of the scrolling, local occupancy grid will determine the size of relevant places and paths.



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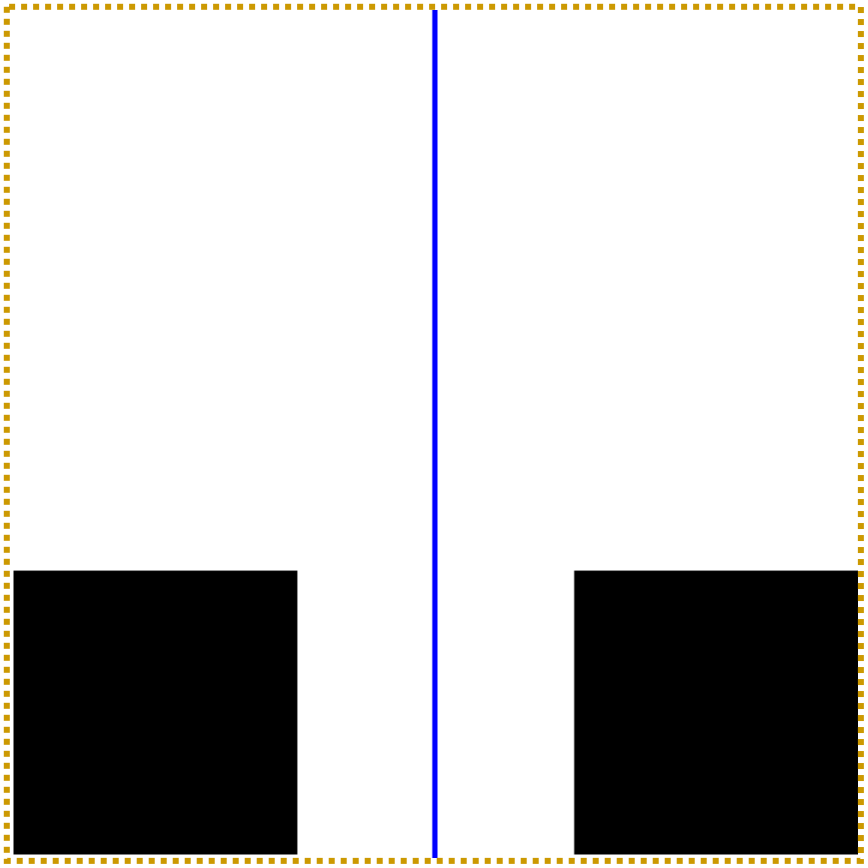
Extending the Voronoi Graph

- Voronoi graphs require N or more nearby obstacles.
  - In our case N=2.

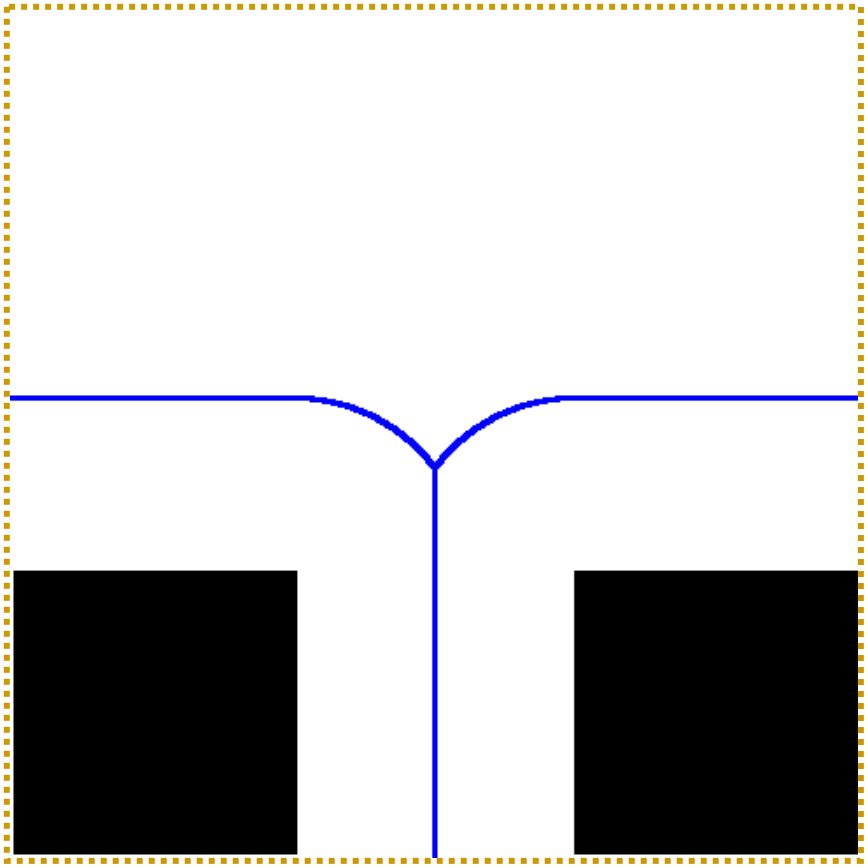
1. This limits the robot to exploring enclosed environments.

2. If following the Voronoi graph, the robot can become lost.

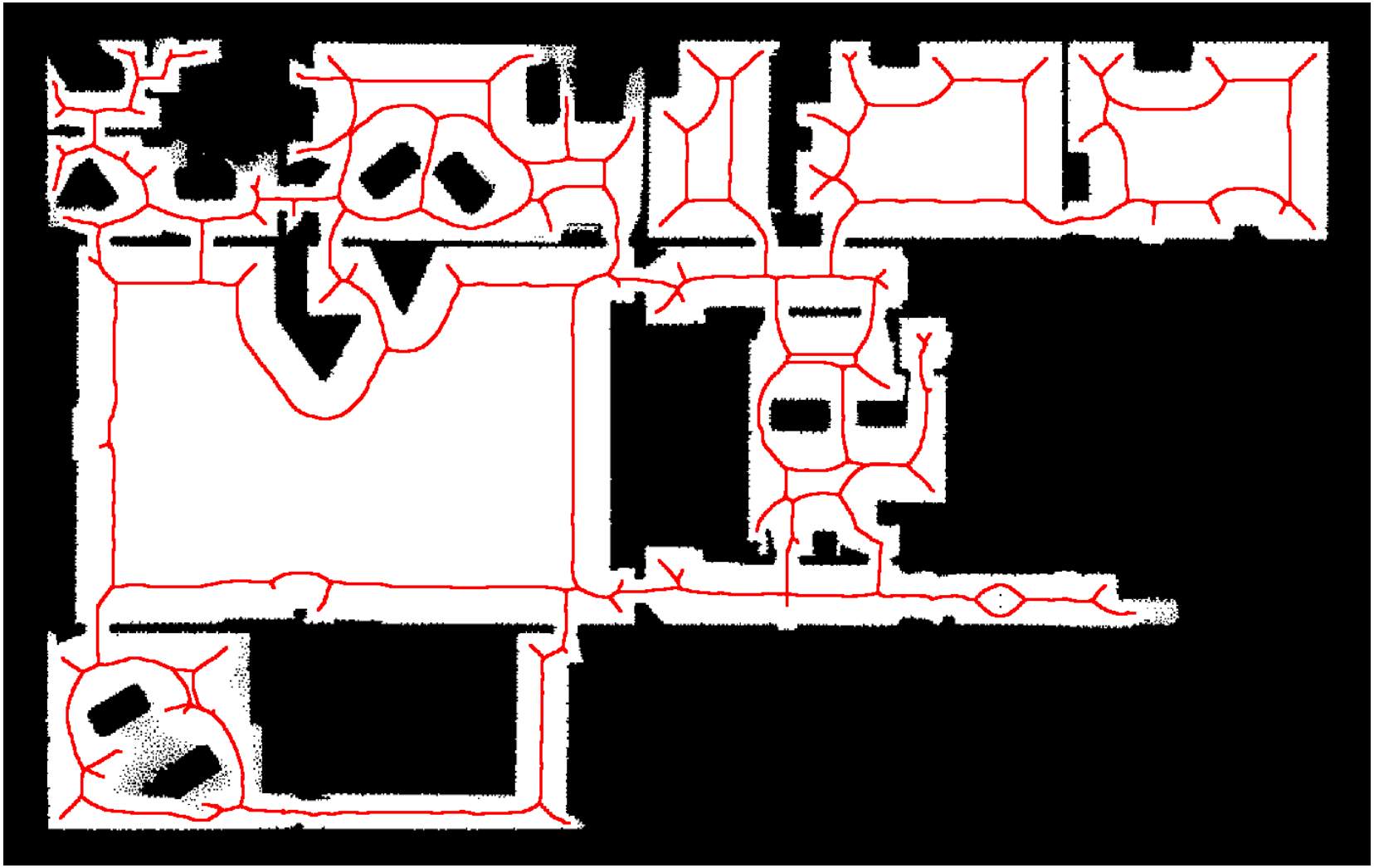


Extended Voronoi Graph

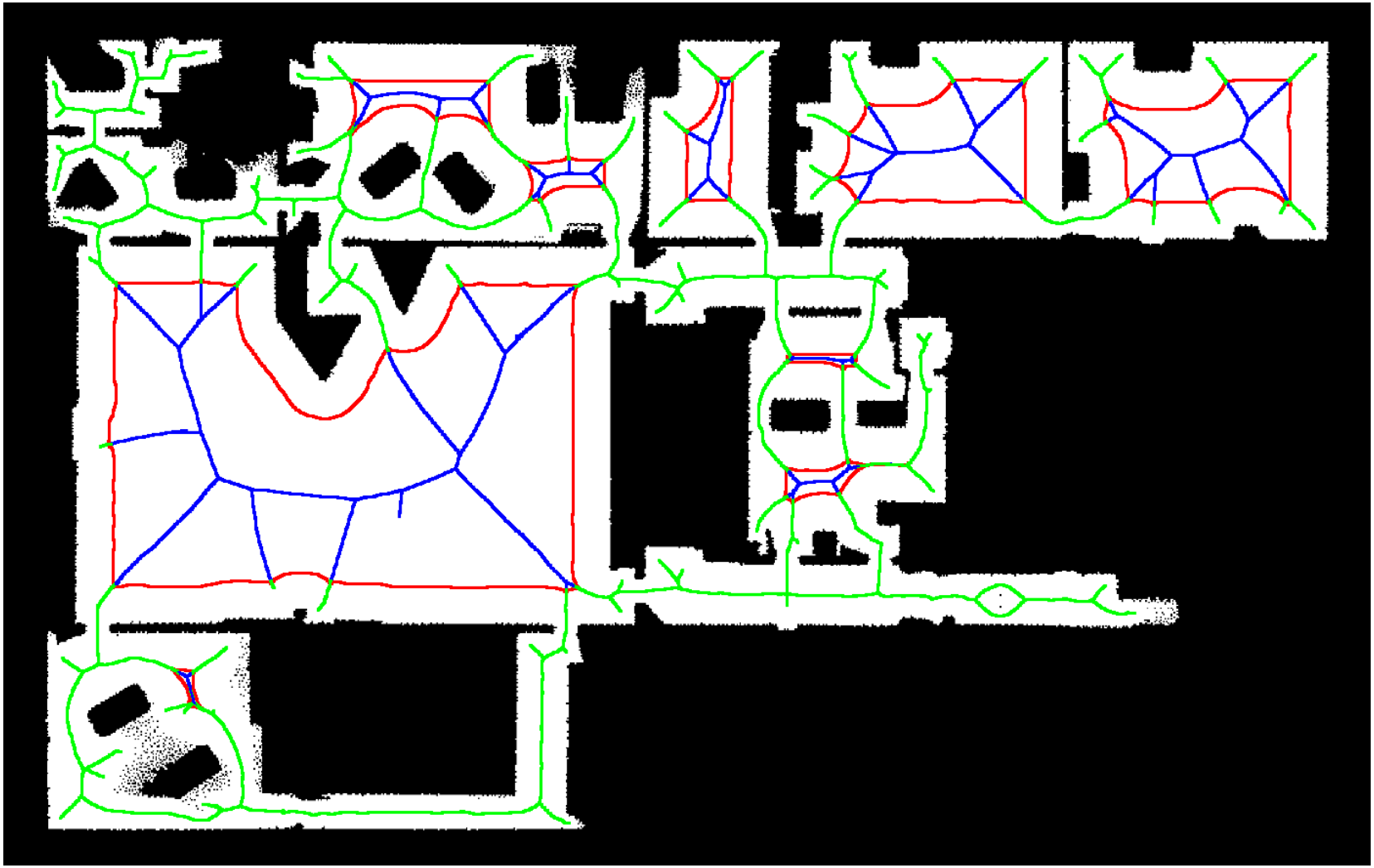
- UNION of:
- Subset of the regular Voronoi graph, where r < *d* < *S*.
  - *d* is distance to nearest obstacle.
  - r is based on the robot's physical body.
  - S is a maximum distance threshold
- The set of points where *d* = *S*.
  - Provides "coastal navigation" when necessary.



Extended Voronoi Graph



Voronoi Graph Comparison



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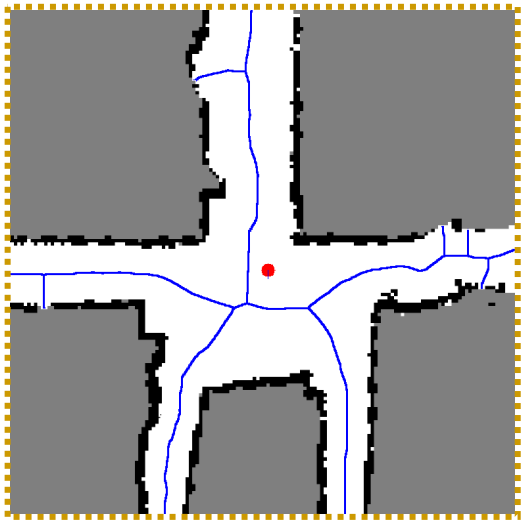
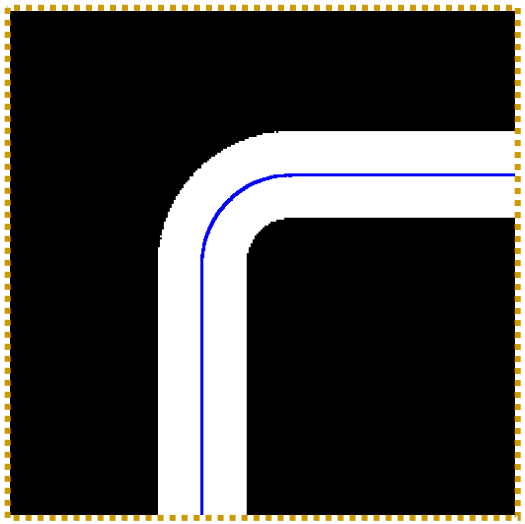
Problems with Places at Junctions

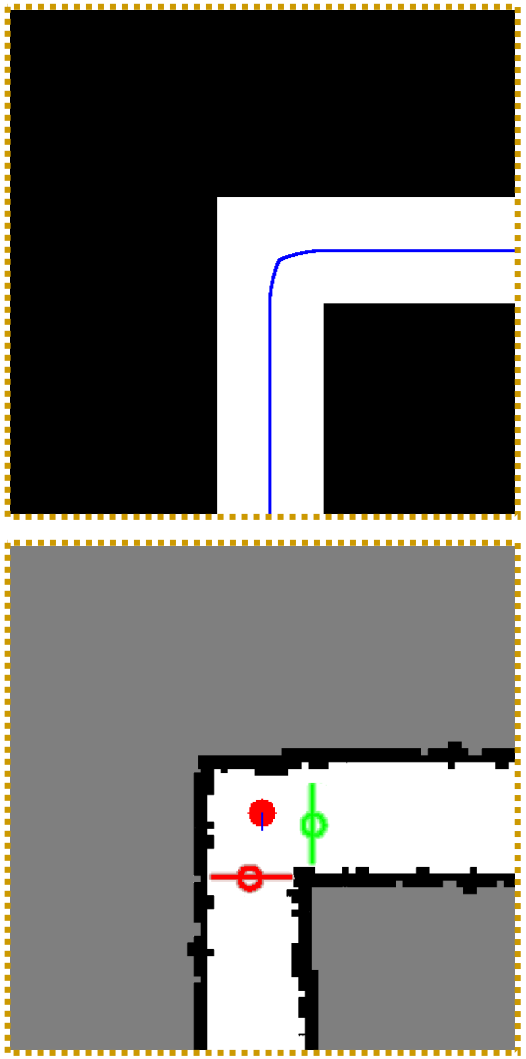
- Junctions are highly susceptible to environmental / sensor noise.
- Some places have multiple junctions.
- Some places do not have junctions.





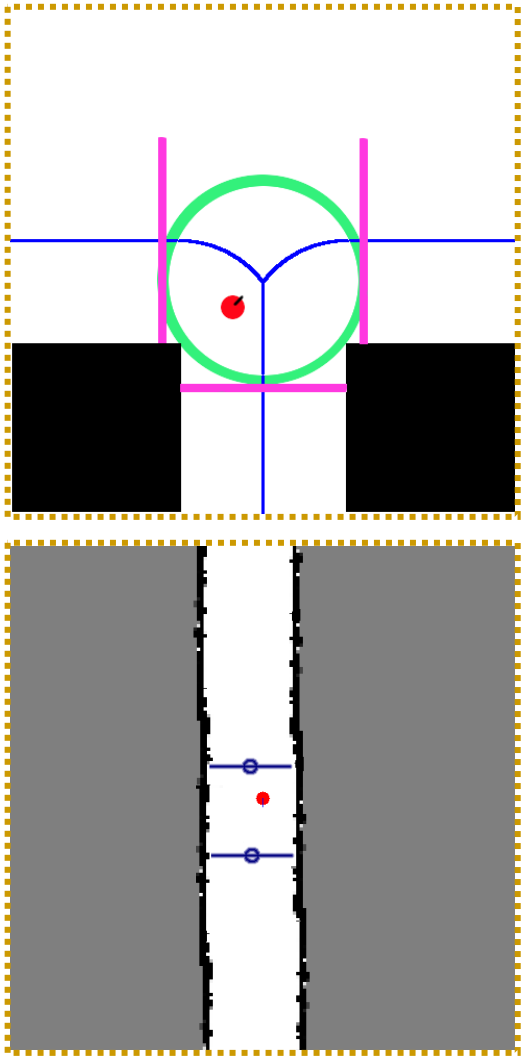
Problems with Paths as Branches

- Using branches to define paths results in multiple places in complex environments.
- Sometimes there are no places in simple environments.
- Our approach uses *gateways* to find paths in the local metrical model.

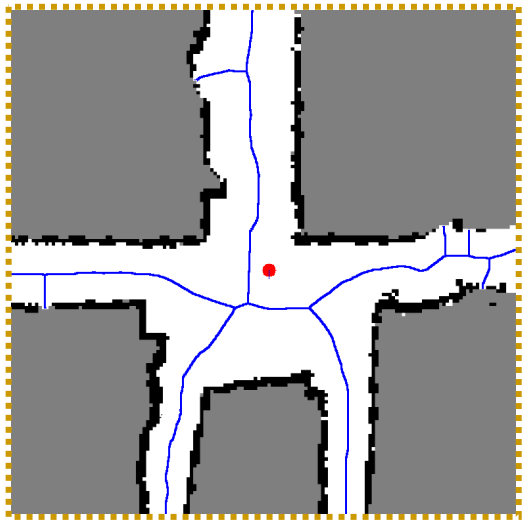


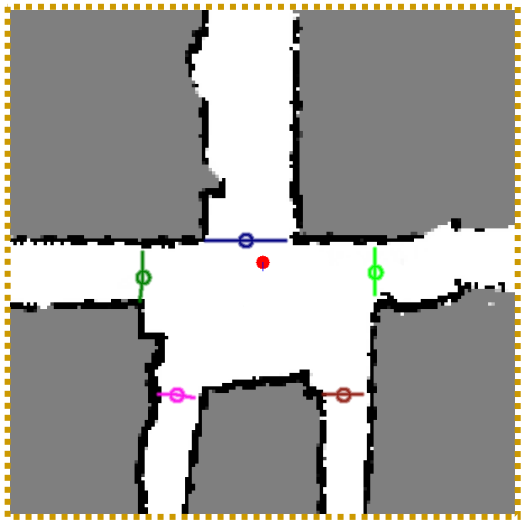
Finding Gateways

- "A gateway occurs where there is at least a partial visual separation between two neighboring areas and the gateway itself is a visual opening to a previously obscured area."
  - Chown et al., "PLAN" paper, 1995
- In previous work, we used gateways to determine the local topology at places.
- Multiple valid gateway definitions exist.
  - See paper for our formal definition.
- Gateways can also be determined at non-places.



Gateways in Complex Places

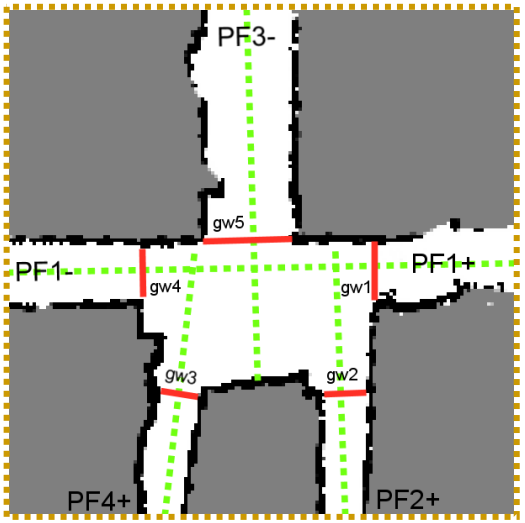


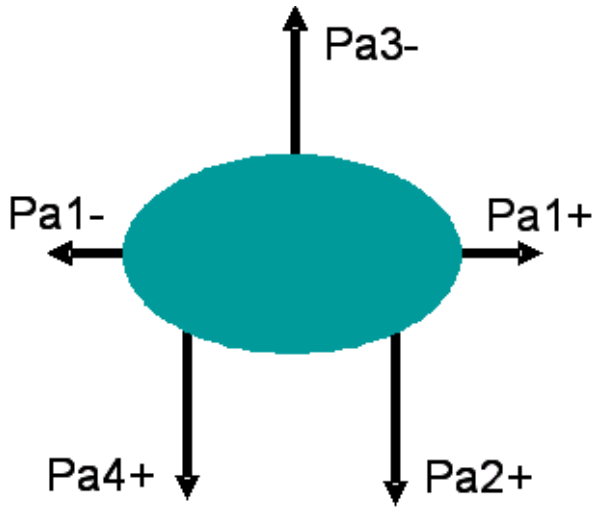


- Our gateway algorithm even works in complex intersections.

Defining Paths

- Each gateway is associated with exactly 1 path.
- If exactly 2 gateways are unambiguously aligned, they belong to the same path.
  - Path passes through the place.
- Otherwise, that path terminates at the place.





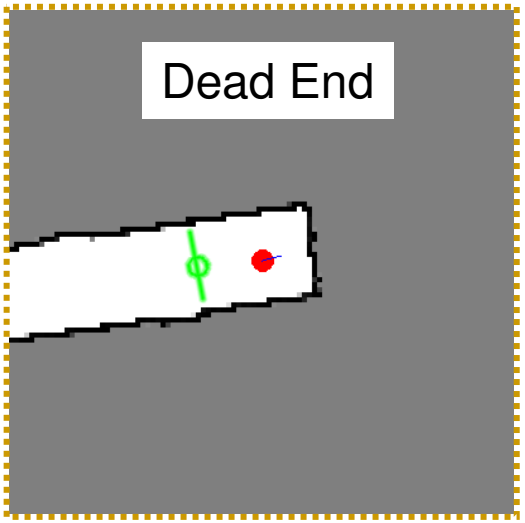
Detecting Places

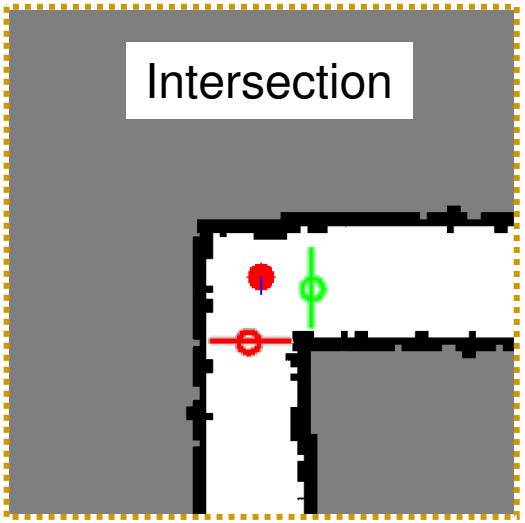
- The robot IS NOT at a place when:
  - Exactly 1 path

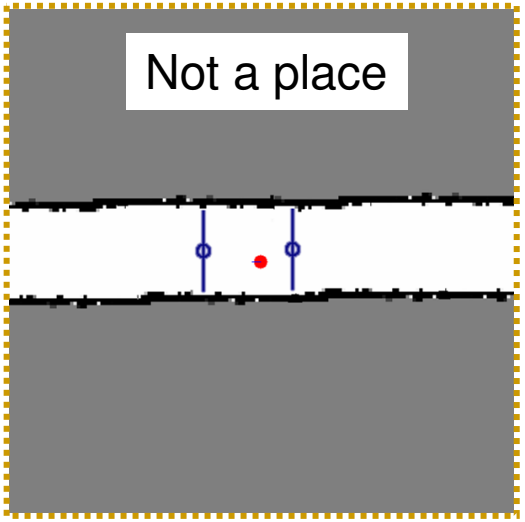
  AND

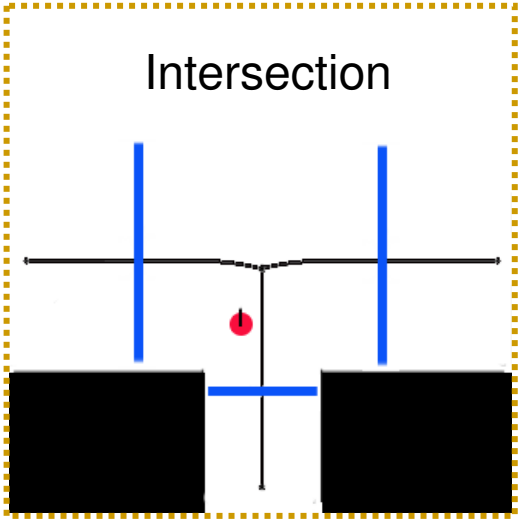
  - Exactly 2 gateways
- Otherwise, the robot IS at a place.
  - enclosed places
    - Number of paths = 0
  - dead-ends
    - Number of gateways = 1
  - intersections
    - Number of paths > 1

Place Detection Examples







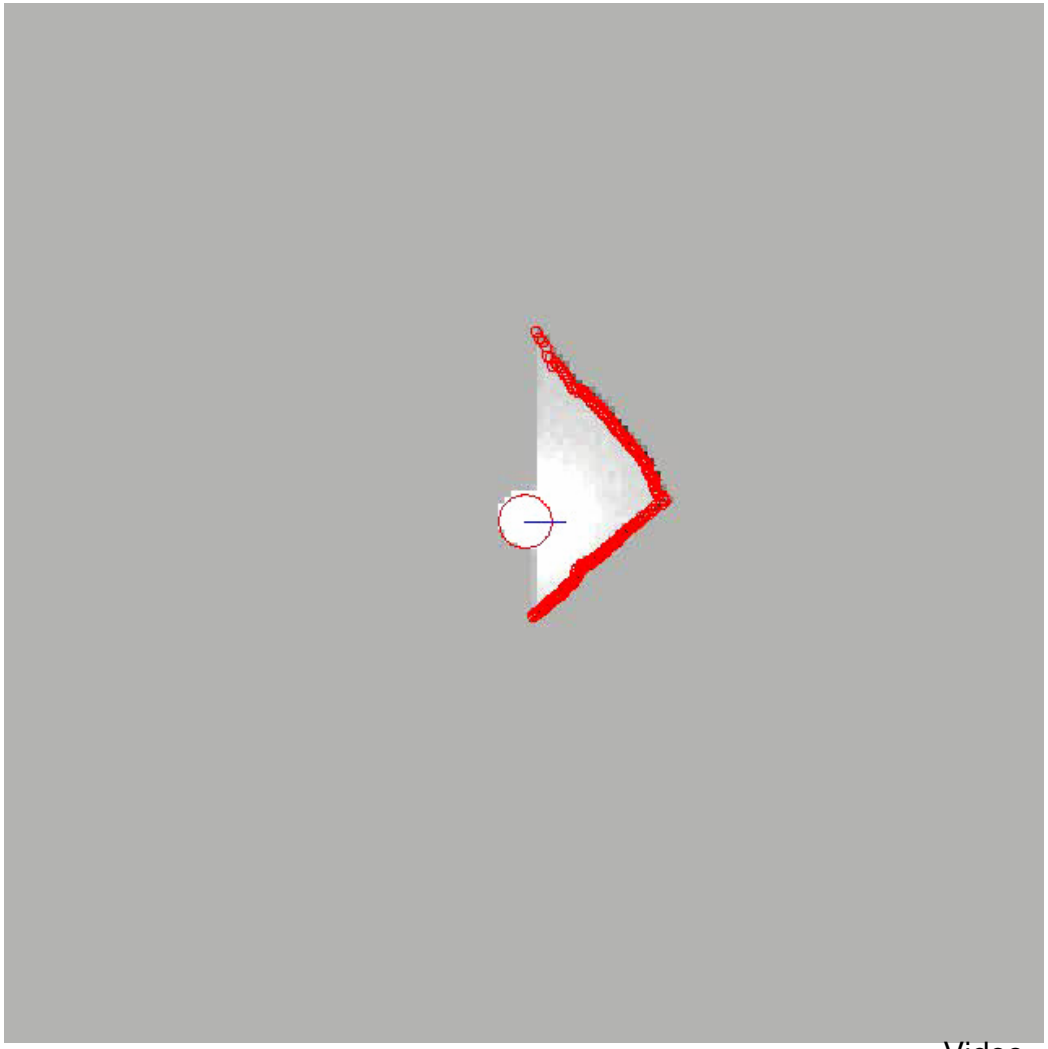


Conclusion

- Our solution achieves reliable autonomous topological place detection (finding intersections, dead-ends, and open doors).
- Our method handles more environments.
  - Extended Voronoi graph handles both enclosed and non-enclosed environments.
- Previous false positive and false negative place detections are overcome.
  - Better pruning technique
  - Define places using gateways and paths not Voronoi junctions
  - Using our gateway algorithm, a robot can even detect complex intersections as single places with non-trivial local topologies.

Thank You

http://www.cs.utexas.edu/~robot



Video