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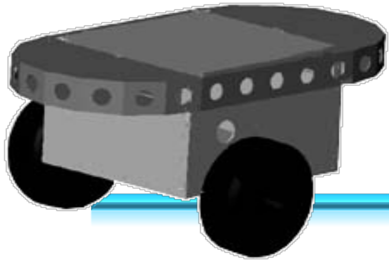
CSCE 574 ROBOTICS

Coverage

Ioannis Rekleitis

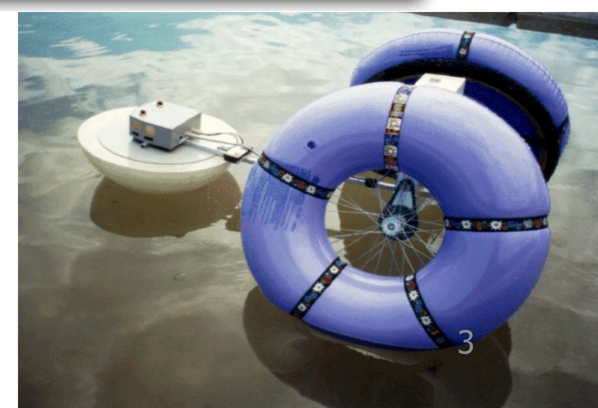
Coverage

- A task performed quite often in everyday life:
  - Cleaning
  - Painting
  - Plowing/Sowing
  - Tile setting
  - etc.



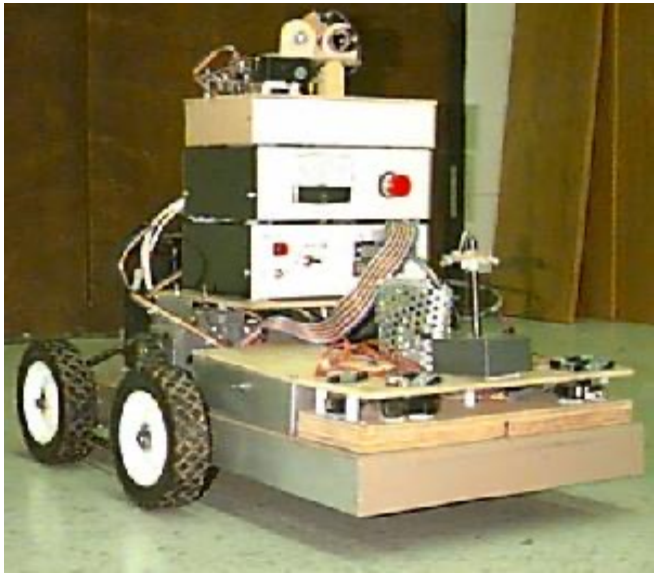
Motivation

Humanitarian Demining



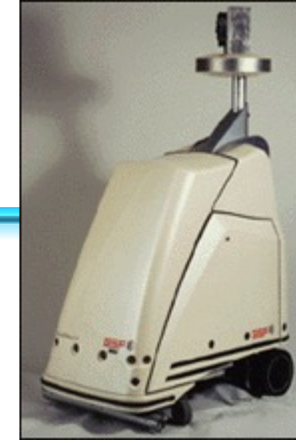
Motivation

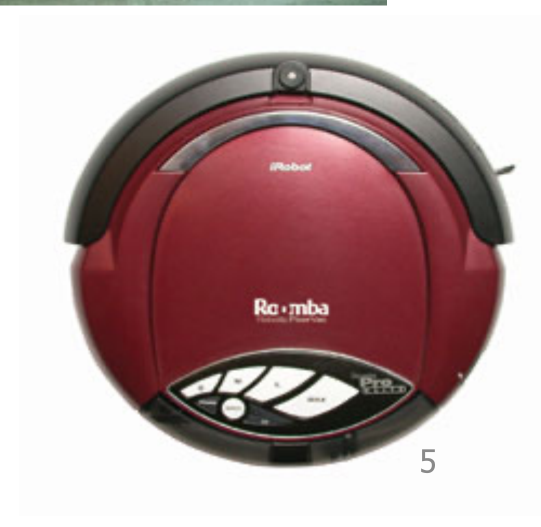
Lawn Mowing



Motivation

Vacuum Cleaning





Robotic Coverage

- More than 10 million Roombas sold!
- Automated Car Painting

Roomba Costumes

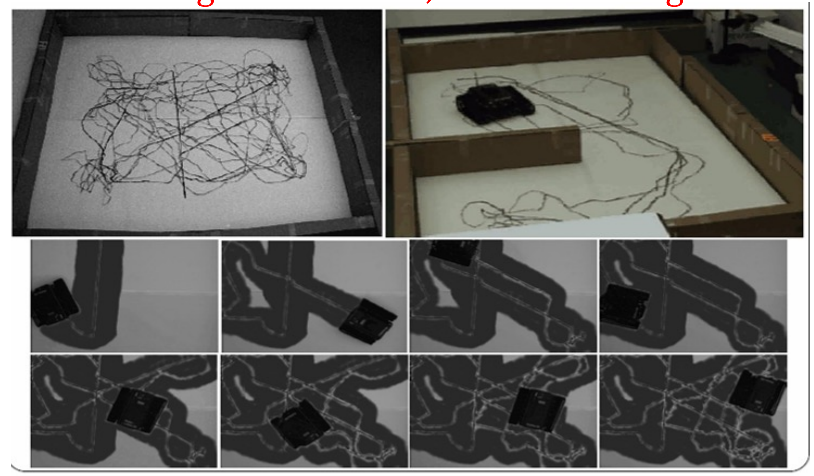
From: http://www.myroombud.com/

Coverage

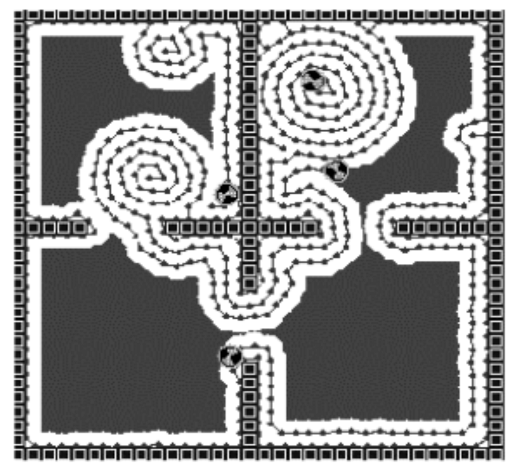
- First Distinction
  - Deterministic **Demining**
  - Random **Vacuum Cleaning**
- Second Distinction
  - Complete
  - No Guarantee
- Third Distinction
  - Known Environment
  - Unknown Environment

Non-Deterministic Coverage

S. Koenig Ant Robotics, terrain coverage

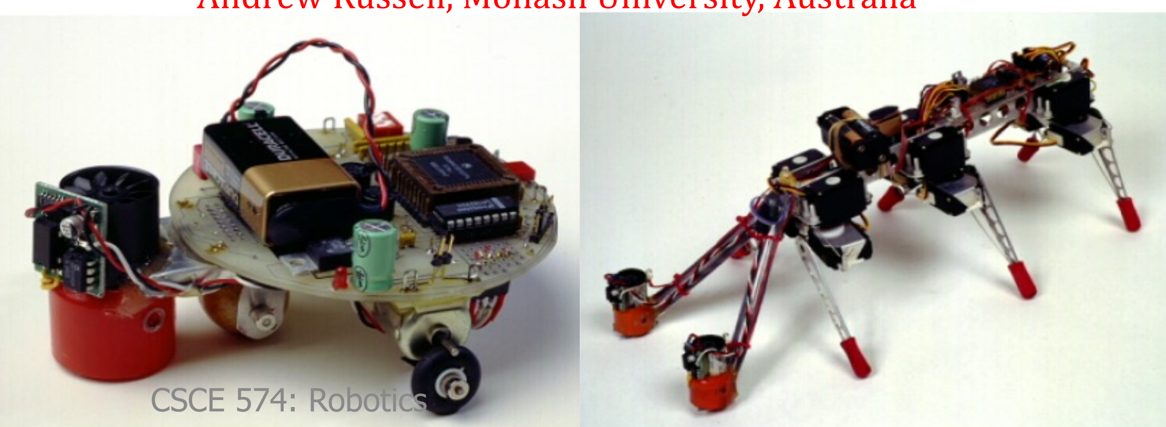


- Complete Random Walk
- Ant Robotics
  - Leave trail
  - Bias the behavior towards or away from the trails



Ant Robotics: I. Wagner, IBM & Technion

Andrew Russell, Monash University, Australia



Deterministic Coverage

- Complete Algorithm
- Guarantees Complete Coverage

Cell-Decomposition Methods

Two families of methods:

- Exact cell decomposition
  The free space F is represented by a collection of non-overlapping cells whose union is exactly F
  Examples: trapezoidal and cylindrical decompositions

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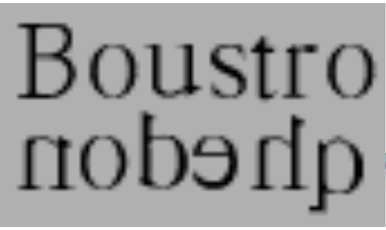
BOUSTROPHEDON CELLULAR DECOMPOSITION

The way of the Ox!

Ioannis Rekleitis



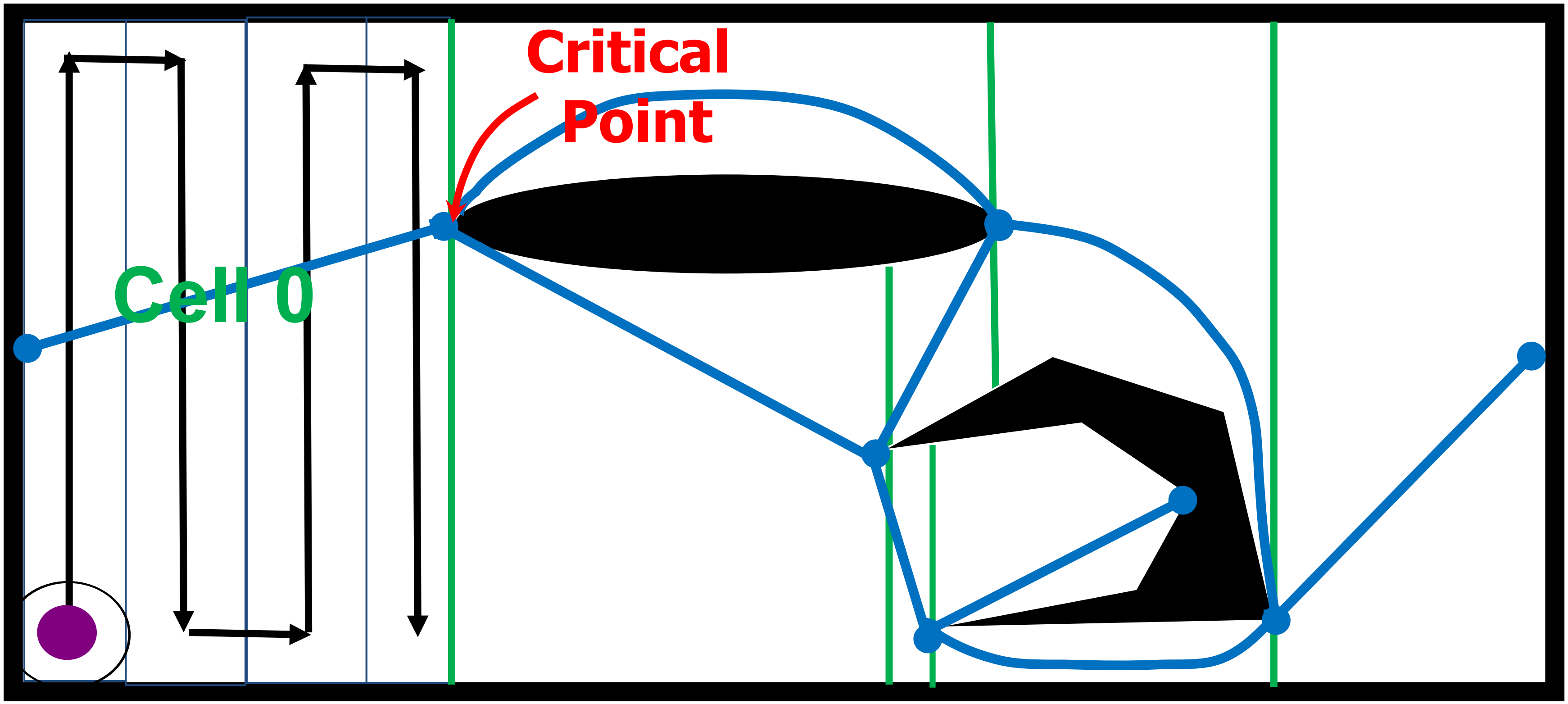
Single Robot Coverage

- Deterministic algorithm
- Guarantee of completeness
- Sensor based
- Unknown Environment

•Seed spreader algorithm: Lumelsky et al, "Dynamic path planning in sensor-based terrain acquisition", IEEE Transactions on Robotics and Automation, August 1990.

•Boustrophedon algorithm: Choset and Pignon, "Coverage path planning: The boustrophedon cellular decomposition", International Conference on Field and Service Robotics,1997.

Single Robot Coverage



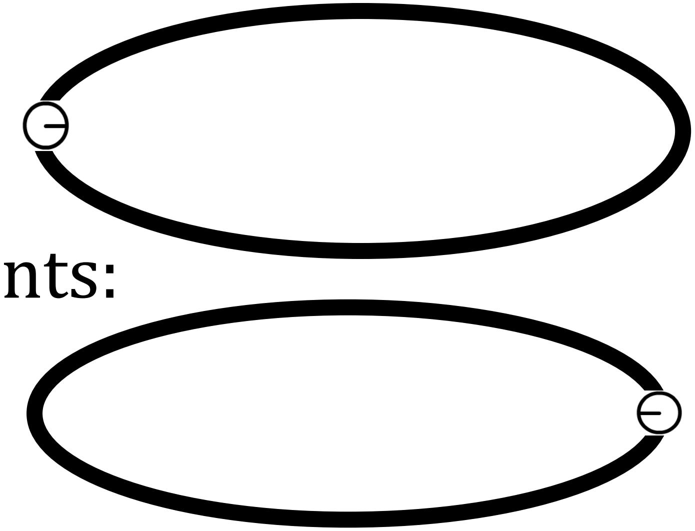
Direction of Coverage

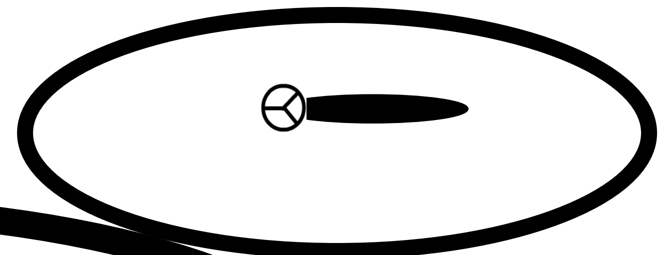
Cellular Decomposition

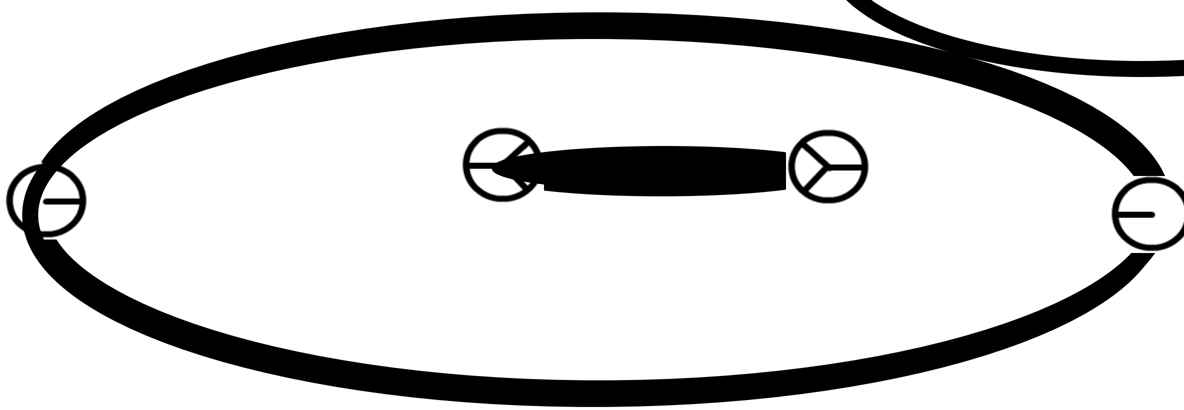
Reeb graph
Vertices: Critical Points
Edges: Cells

Critical Points

- There are four types of critical points:
  - Forward Concave critical point
  - Reverse Concave critical point
  - Reverse Convex critical point
  - Forward Convex critical point







Direction of Coverage

Efficient Coverage

- Find an order for traversing the Reeb graph such that the robot would not go through a cell more times than necessary

Solution

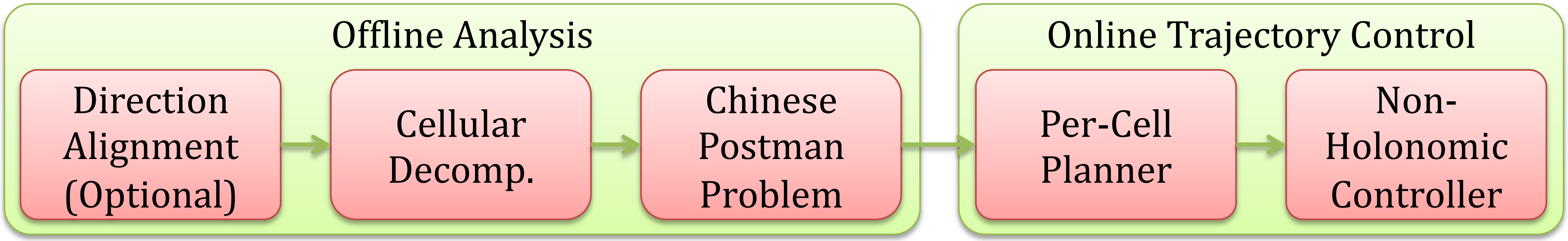
- Use the Chinese Postman Problem

Chinese Postman Problem

- The Chinese postman problem (CPP), is to find a shortest closed path that visits every edge of a (connected) undirected graph. When the graph has an Eulerian circuit (a closed walk that covers every edge once), that circuit is an optimal solution.

See: J. Edmonds and E.L. Johnson, Matching Euler tours and the Chinese postman problem, Math. Program. (1973).

Offline Analysis Algorithm



Offline Analysis Algorithm

Offline Analysis: Direction Alignment (Optional) → Cellular Decomp. → Chinese Postman Problem → **Online Trajectory Control**: Per-Cell Planner → Non-Holonomic Controller

- Input: binary map separating obstacle from free space
- Boustrophedon Cellular Decomposition (BCD)

: intersections = vertices

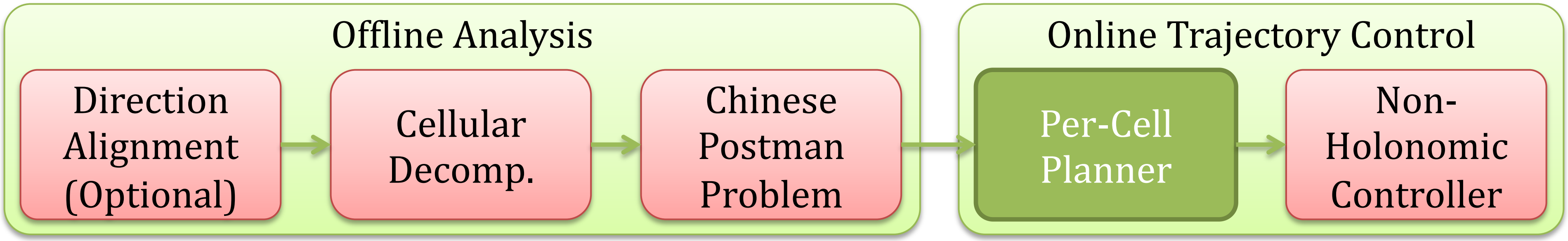
: cells = edges

Offline Analysis Algorithm (cont.)

Offline Analysis: Direction Alignment (Optional) → Cellular Decomp. → **Chinese Postman Problem** → **Online Trajectory Control**: Per-Cell Planner → Non-Holonomic Controller

- Chinese Postman Problem
  - Eulerian circuit, i.e. *single* traversal through all cells (edges)

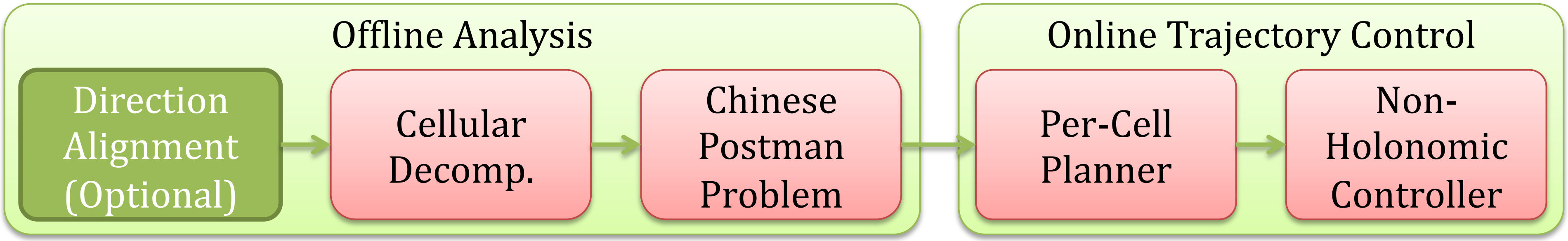
Per-Cell Coverage Planner



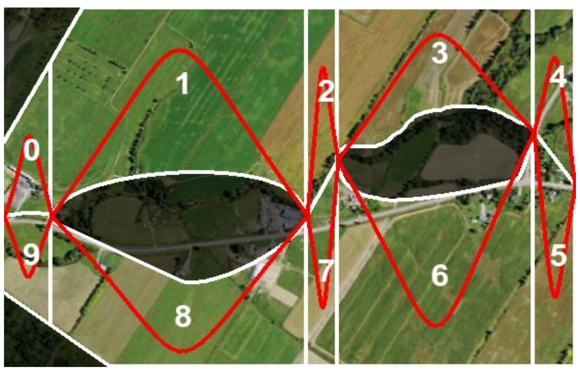
- Seed Spreader: piecewise linear sweep lines

- Footprint width

Coverage Direction Alignment



- Static alignment methods



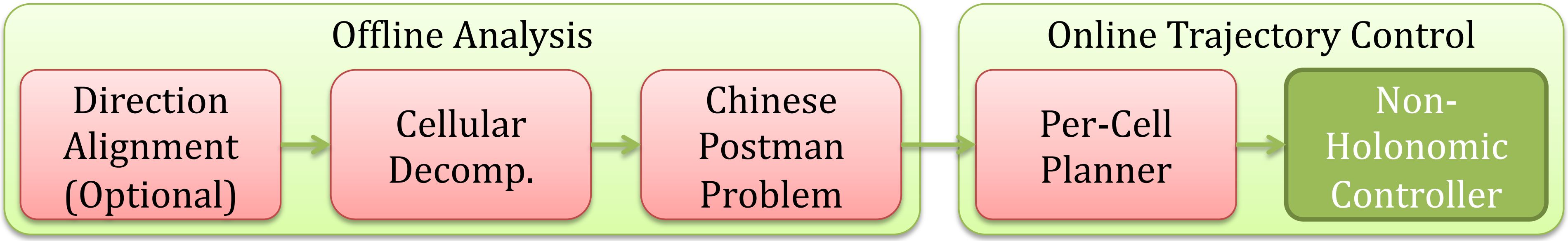
Default

Obstacle Boundaries

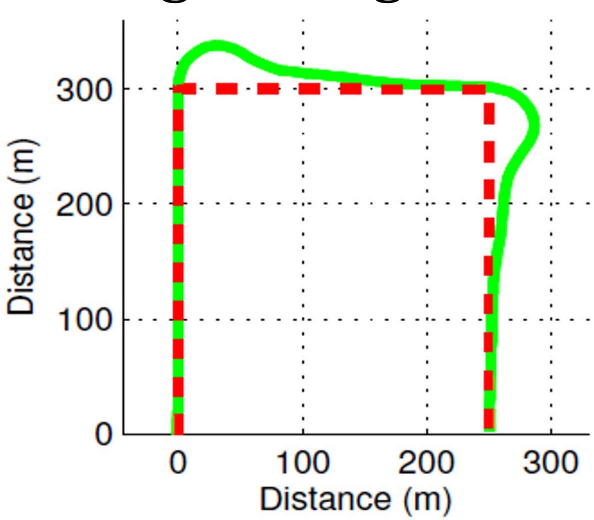
Free Space Distribution

- Alignment with average wind heading (pre-flight)

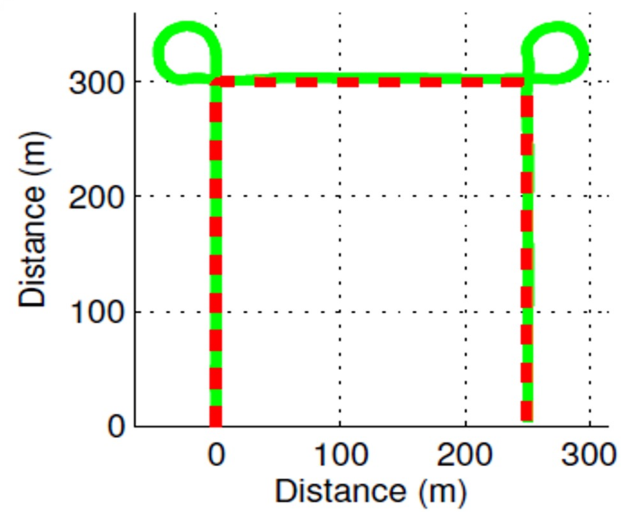
Non-Holonomic Robot Controller



- Turning strategies



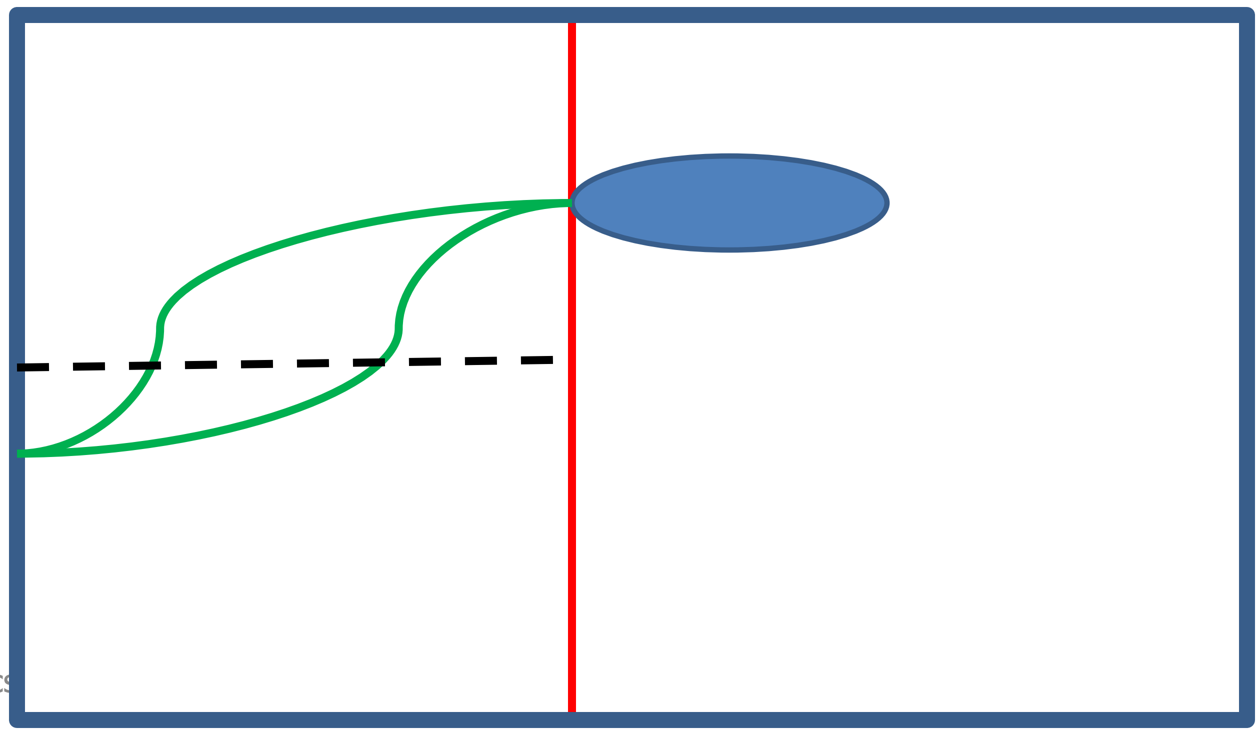
Greedy Waypoint Controller



Curlicue Controller

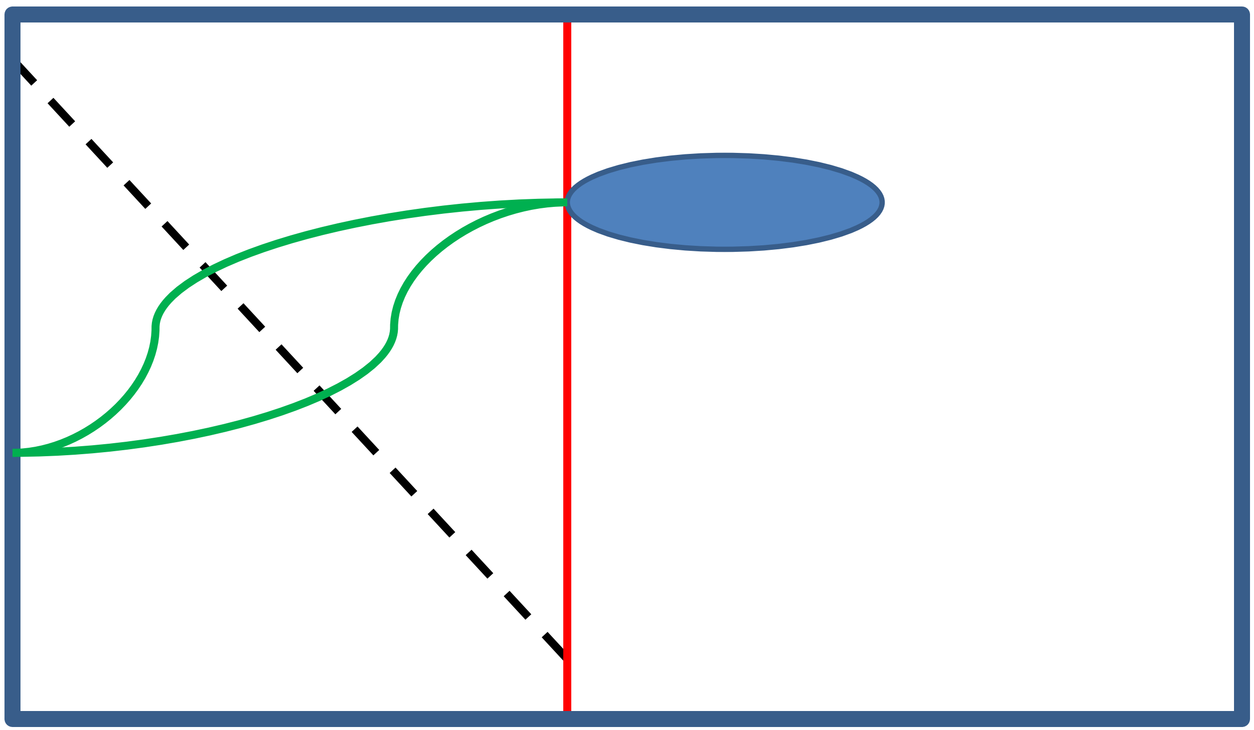
Chinese Postman Problem

- The solution of the CPP guarantees that no edge is doubled more than once
- That means some cells have to be traversed twice
- Cells that have to be traversed/covered are divided in half



Double Coverage of a Single Cell

- By dividing the cell diagonally we control the beginning and end of the coverage



Double Coverage of a Single Cell

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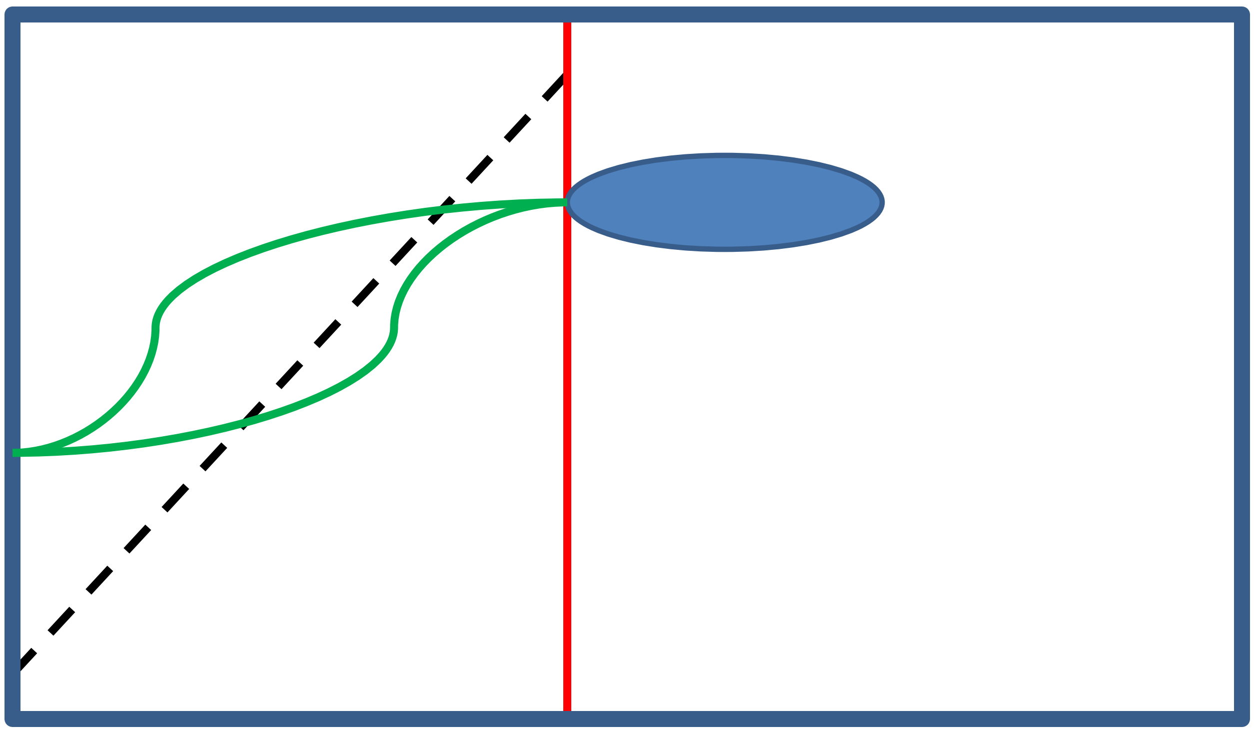
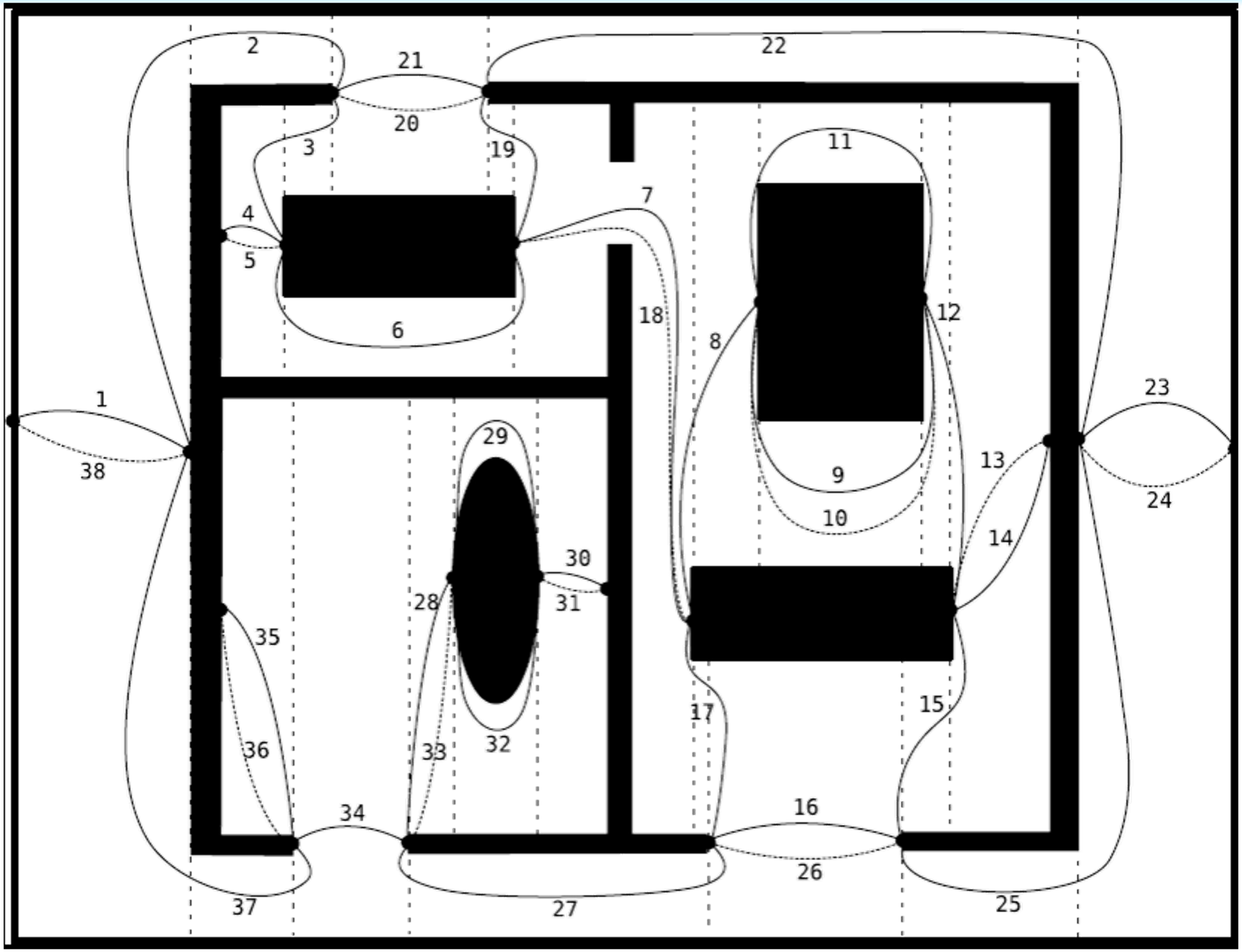


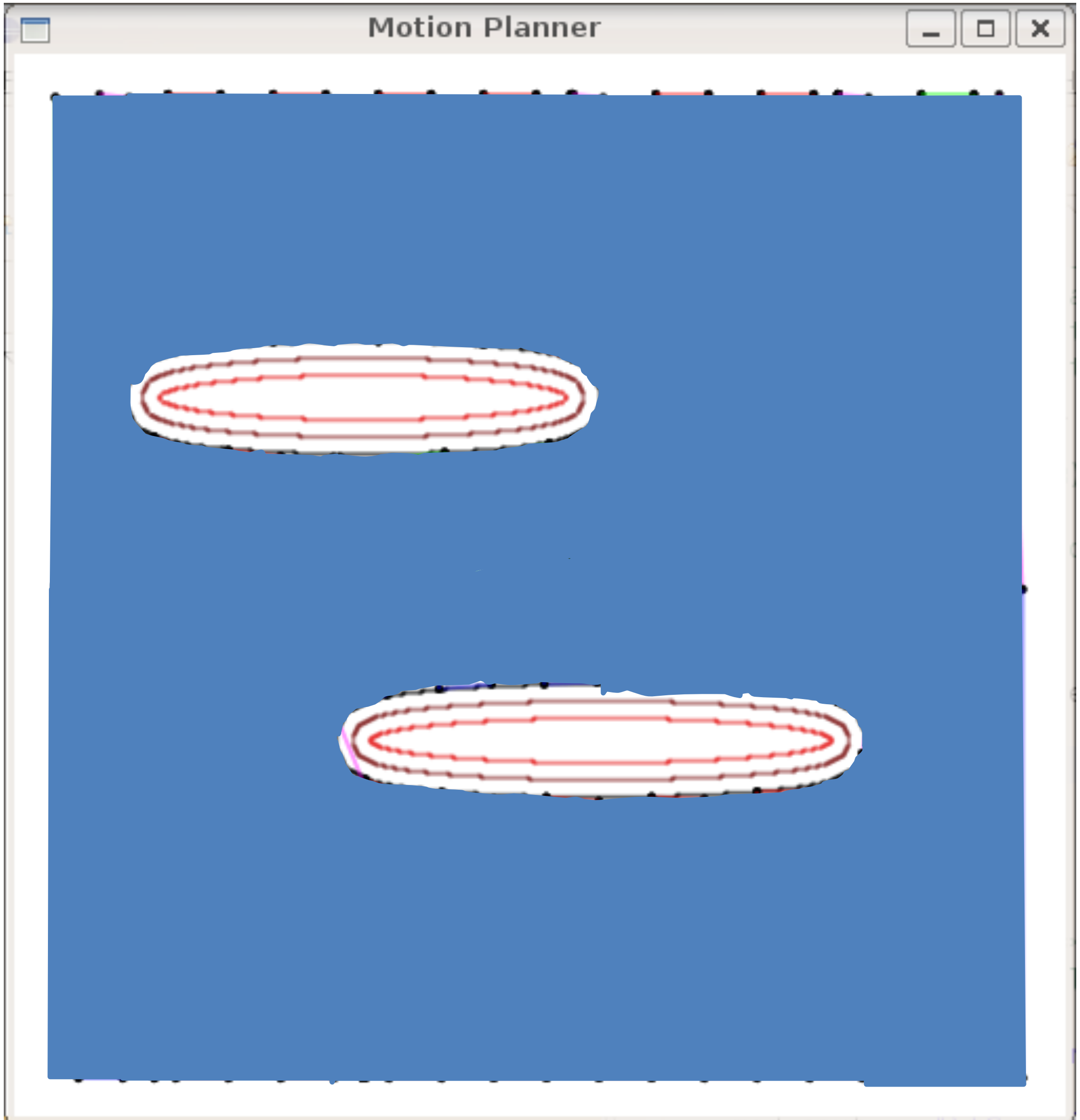
Efficient Coverage Algorithm

- Given a known environment:
  - Calculate the Boustrophedon decomposition
  - Construct the Reeb graph
  - Use the Reeb graph as input to the Chinese Postman Problem (CPP)
  - Use the solution of the CPP to find a minimum cost cycle traversing every edge of the Reeb graph
  - For every doubled edge divide the corresponding cell in half
  - Traverse the Reeb graph by covering each cell in order

Traversal order of the Reeb graph



Example



Example: Boustrophedon Decomposition