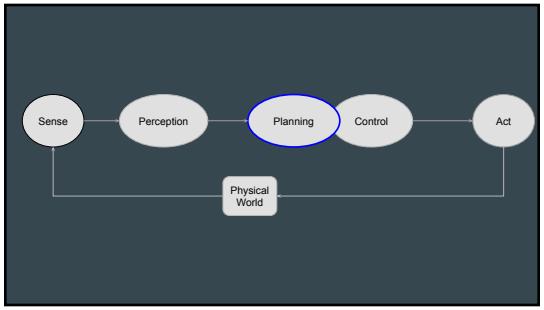
CS4501
Robotics for Soft Eng

•••

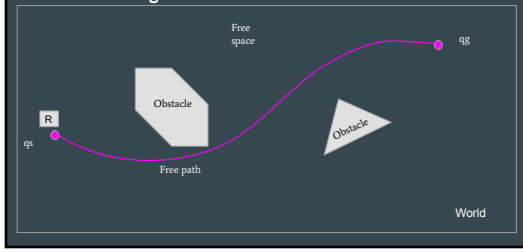
Motion Planning



Motion Problem

- Given
  - World Space W
  - Obstacle Regions O
  - Robot State R
  - Starting and Ending Configurations qs, qg
- Find a path that modifies R so that
  - From qs to qg
  - While staying in W
  - Without hitting any obstacle O
  - [other constraints]

Motion Planning Problem



Motion Planning Families

- Reactive
- Model-based

Work under different assumptions about sensor types and world models available

Motion Planning Families

- Reactive
  - Online
  - Fast, non-optimal

Bug Algorithms

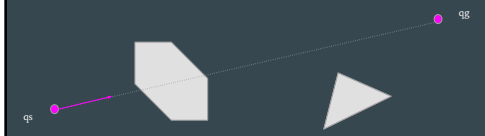
Robot

- Is modeled as a bounded point
- Can sense its location precisely
- Can sense contact with obstacles
- Can compute direction towards goal and distance between two points
- Does not know location of obstacles in advanced

Bug Algorithm 1

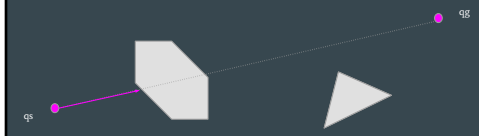
Repeat until Robot-pose = Goal

Bug Algorithm 1



Repeat until Robot-pose = Goal
Head towards goal

Path Planning Simplified: Bug Algorithm 1



Repeat until Robot-pose = Goal
Head towards goal
If obstacle detected then
Navigate next to wall to the left until heading towards goal is possible

Bug Algorithm 1

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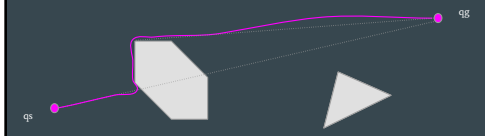
Bug Algorithm 1



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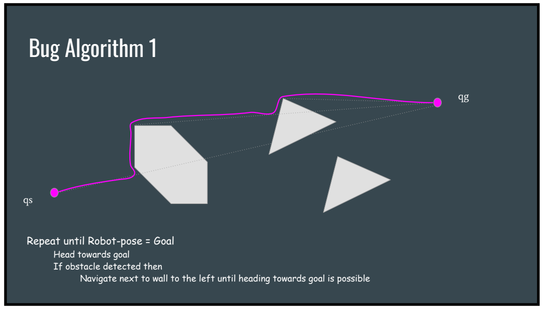
Bug Algorithm 1
qg
qs
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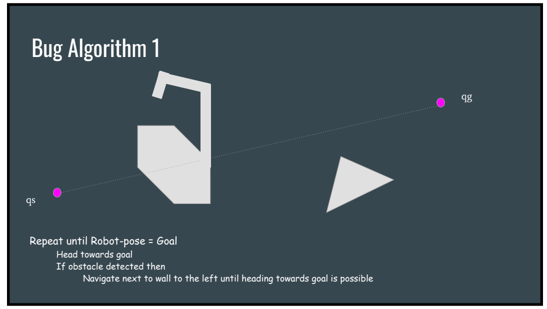
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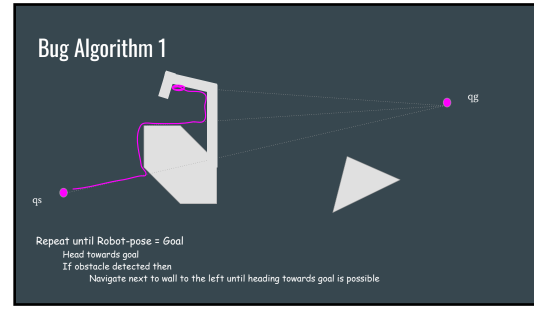
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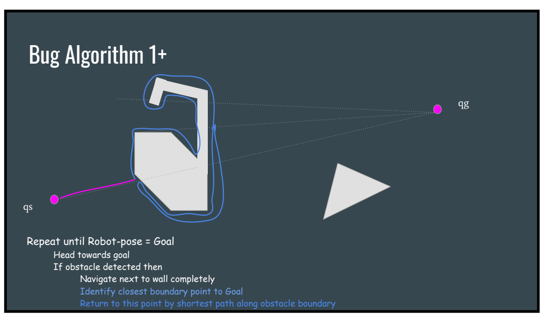
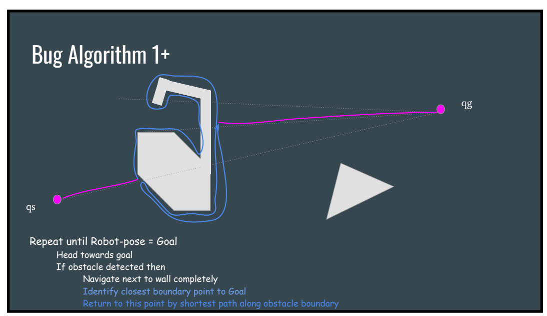

Bug Algorithm 1+
qg
qs
Repeat until Robot-pose = Goal
Head towards goal
If obstacle detected then
Navigate next to wall completely
Identify closest boundary point to Goal
Return to this point by shortest path along obstacle boundary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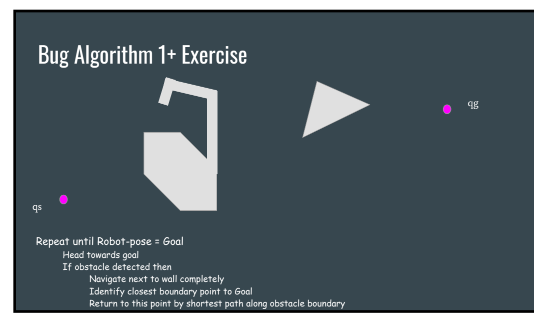
Bug Algorithm 1+ Exercise
qg
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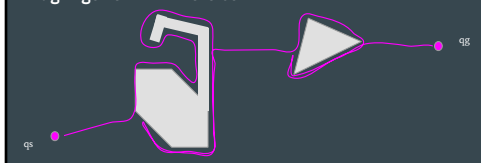
Bug Algorithm 1+ Exercise



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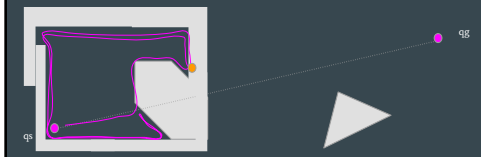
Bug Algorithms 1++

Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
  - Navigate next to wall completely
  - Identify closest boundary point to Goal, if direction towards the Goal hits obstacle break
  - Return to this point by shortest path along obstacle boundary

Bug Algorithms 1++



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Bug Algorithm 1++

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- Head towards goal
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  - Return to this point by shortest path along obstacle boundary

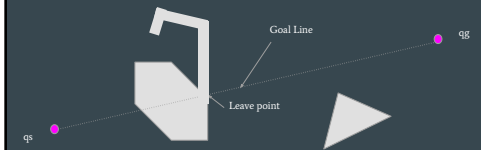
Distance **T** traveled by Bug-1 (based on D distance between qs and qg)
- Lower bound:
- Upper Bound:

Bug Algorithm 1++

Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
  - Navigate next to wall completely
  - Identify closest boundary point to Goal, if direction towards the Goal hits obstacle break
  - Return to this point by shortest path along obstacle boundary

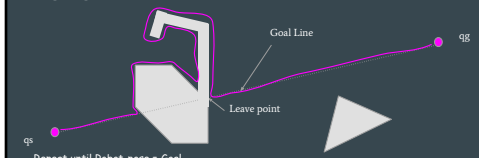
Distance T traveled by Bug-1 (based on D distance between qs and qg)
- Lower bound: *T >= D*
- Upper Bound: *T <= D + 1.5 ∑(perimeter polygons)*

Bug Algorithm 2



Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
  - Repeat
    - Navigate next to wall (to the left)
  - Until Goal Line crossed at Leave point closer to goal on the same side than before

Bug Algorithm 2



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Until Goal Line crossed at Leave point closer to goal on the same side than before

Bug Algorithm 2

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Until Goal Line crossed at Leave point closer to goal on the same side than before

Bug Algorithm 2 Exercise

Repeat until Robot-pose = Goal
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Until Goal Line crossed at Leave point closer to goal on the same side than before

Path Planning Simplified: Bug Algorithm 2 Exercise

Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
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Until Goal Line crossed at Leave point closer to goal on the same side than before

Bug Algorithm 2

Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
  - Repeat
    - Navigate next to wall (to the left)

Until Goal Line crossed at Leave point closer to goal on the same side than before

Distance T traveled by Bug-2 (based on D distance between qs and qg)
- Lower bound:
- Upper Bound:

Bug Algorithm 2

Repeat until Robot-pose = Goal
- Head towards goal
- If obstacle detected then
  - Repeat
    - Navigate next to wall (to the left)

Until Goal Line crossed at Leave point closer to goal on the same side than before

Distance T traveled by Bug-2 (based on D distance between qs and qg)
- Lower bound: $T >= D$
- Upper Bound: $T <= D + 0.5 \sum$*(Perimeters of obstacles intersected by goal line * number of times lines intersects each obstacle)*

Bug Algorithm 2 Exercise

Repeat until Robot-pose = Goal
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- If obstacle detected then
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    - Navigate next to wall (to the left)
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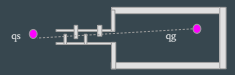

Bug Algorithm 2 Exercise

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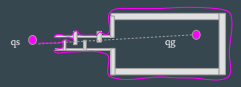
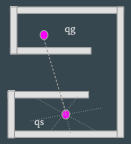


Relaxing Bug Algorithm assumptions

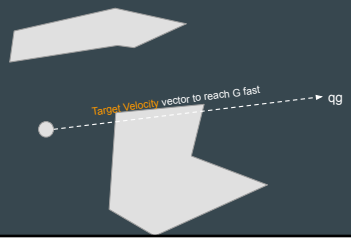


Robot
- Is modeled as a bounded point
- Can sense its location precisely
- Can sense contact with obstacles - can sense more…
- Can compute direction towards goal and distance between two points
- Does not know location of obstacles, has more memory

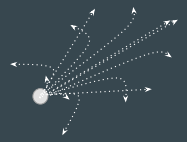
Motion Problem

- Reactive
  - Bug
  - Dynamic windows
- Model-based

Dynamic Windows

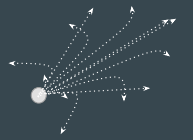


Dynamic Windows



For each time slice t
Enumerate allowed velocities in

Dynamic Windows

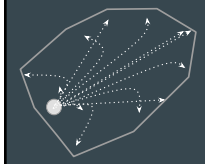


For each time slice **t**
Enumerate allowed velocities in

Robot
Physical Model

Racing drone
Values of the high power drone (Gemo-Copter):
- climb rate: cca 40 m/s or 140 km/h
- acceleration from 0 to 100 km/h (vertical): far below 2 s
- duration to reach 100 meters above the ground from the hover: 2,8 s
- maximum acceleration: 3,6 g or 36 m/s2
- take off weight: 923 g
- maximum power: 2.250 Watt
- power to weight ratio: 2438 W/kg

Dynamic Windows

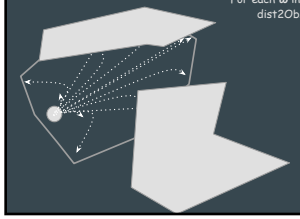


For each time slice **t**
For each **v** in [curr.v - maxacc(t), curr.v + maxacc(t)]

If (v < maxV and v > minV)
validVelocities.add(**v**)

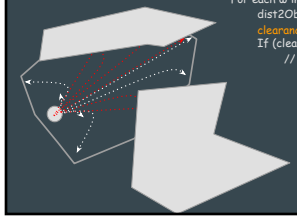
For each **ω** in [curr.ω - maxacc(t), curr.ω + maxacc.(t)]
If (ω < maxω and ω > minω)
validAngVelocities.add(ω)

Dynamic Windows



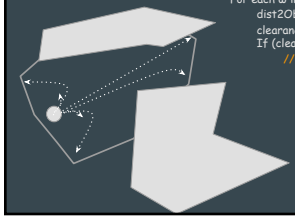
For each **v** in validVelocities
For each **ω** in validAngVelocities
dist2Obstacle = computeDist(v, ω, laserScan())

Dynamic Windows



For each **v** in validVelocities
For each ω in validAngVelocities
dist2Obstacle = computeDist(v, ω, laserScan())
clearance = dist2Obstacle - breakDist(v,ω)
If (clearance > 0)
// non-colliding velocities

Dynamic Windows



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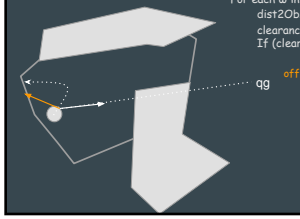
Dynamic Windows

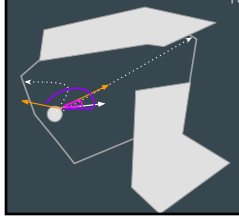


For each **v** in validVelocities
For each ω in validAngVelocities
dist2Obstacle = computeDist(v, ω, laserScan())
clearance = dist2Obstacle - breakDist(v)
If (clearance > 0)

offHeading = headingDiff(robot.pose, qg, v, **ω**)

qg

Dynamic Windows



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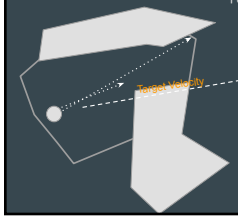
            offHeading = headingDiff(robot.pose, qg, v, ω)
qg
```

Dynamic Windows

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        If (clearance > 0)

            offHeading = headingDiff(robot.pose, qg, v, ω)

            offVel = abs(targetVelocity - v))
```
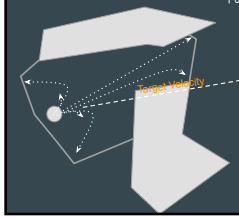

Dynamic Windows

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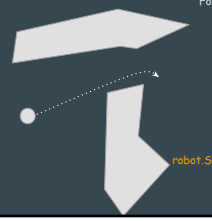
        If (clearance > 0)

            offHeading = headingDiff(robot.pose, qg, v, ω)

            offVel = abs(targetVelocity - v))

            output = ka*clearance + kb* offHeading + kc*offVel
```

Dynamic Windows



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    For each ω in validAngVelocities
        dist2Obstacle = computeDist(v, ω, laserScan())
        clearance = dist2Obstacle - breakDist(v)
        If (clearance > 0)
            offHeading = headingDiff(robot.pose, qg, v, ω)
            offVel = abs(targetVelocity - v))
qg          output = ka*clearance + kb* offHeading + kc*offVel
            if (output > chosen)
                chosenV = v
                chosenW = ω
                chosen = output
robot.Speed(chosenV, chosenW)
```
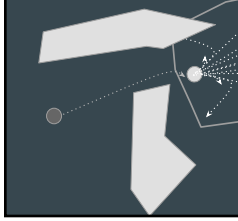

Dynamic Windows



Dynamic Windows

- Velocity planner (clearance, heading, velocity)
- Considers Robot's Dynamics for valid velocities

Motion Planning Families

- Reactive
- Model-based

Path Planning with Models

- Reactive
- Model-based
  - Predictive model of robot actions in **known** world
  - Build simplified representation
  - Search for solution in world representation

Path Planning: Visibility Methods

Assumptions

- Robot modeled as a bounded point
- Can sense its location precisely
- Can compute direction towards goal and distance between two points
- Knows location of obstacles in advanced - **polygonal obstacles**

Path Planning: Visibility Methods

- Assumption: known polygonal obstacles

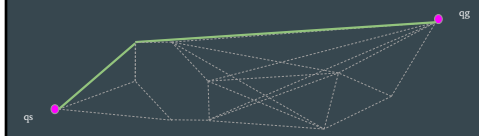
Path Planning: Visibility Methods

- Assumption: known polygonal obstacles
- Connect all vertices without obstacles in between

Path Planning: Visibility Methods

- Assumption: known polygonal obstacles
- Connect all vertices without obstacles in between
- Graph search!

Path Planning: Visibility Methods



- Assumption: known polygonal obstacles
- Connect all vertices without obstacles in between
- Graph search algorithm

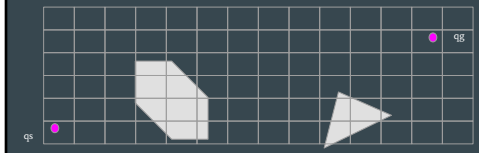
Path Planning: Visibility Methods

When does it fail?

Path Planning with Models

- Reactive
- Model-based
  - Visibility
  - Grid

Path Planning: Grid Methods

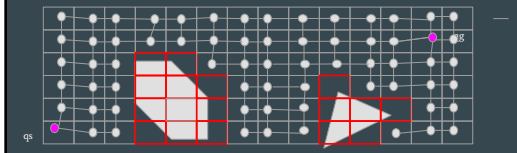


- Discretization of space - resolution

Path Planning: Grid Methods

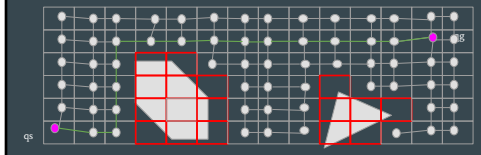
- Discretization of space
- Occupancy checker - probability

Path Planning: Grid Methods



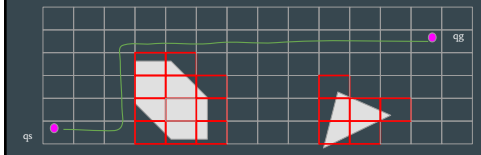
- Discretization of space
- Occupancy checker - probability

Path Planning: Grid Methods



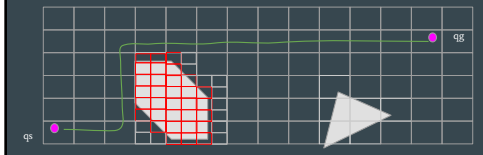
- Discretization of space
- Occupancy checker
- Graph search algorithm on free cells

Path Planning: Grid Methods



- Discretization of space
- Occupancy checker
- Graph search algorithm on free cells
- Dependent on cell dimensions
- Subject to shape of objects

Path Planning: Grid Methods with Refinement

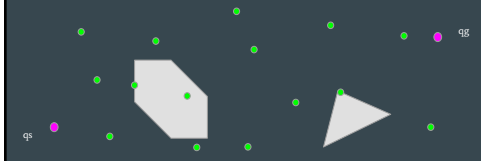


- Discretization of space
- Occupancy checker
- Graph search algorithm on free cells
- Dependent on cell dimensions
- Subject to shape of objects

Path Planning with Models

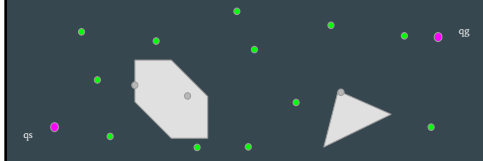
- Reactive
- Model-based
  - Visibility
  - Grid
  - Probabilistic

Path Planning: Probabilistic Roadmap



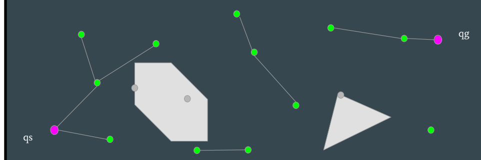
- Random sample of points in space

Path Planning: Probabilistic Roadmap



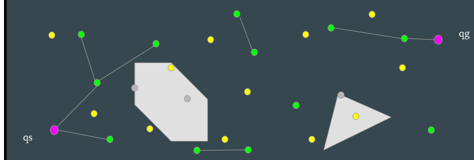
- Random sample of points in space
- Drop samples over obstacles

Path Planning: Probabilistic Roadmap



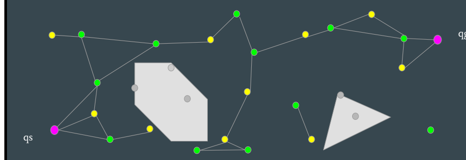
- Random sample of points in space
- Drop samples over obstacles
- Connect samples to k-nearest neighbors

Path Planning: Probabilistic Roadmap



- Random sample of points in space
- Drop samples over obstacles
- Connect samples to k-nearest neighbors
- Sample more points until qs and qg are connected

Path Planning: Probabilistic Roadmap



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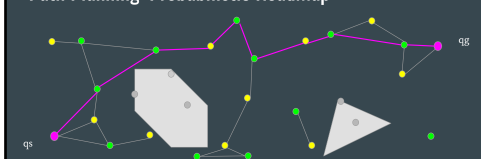
Path Planning: Probabilistic Roadmap



- Random sample of points in space
- Drop samples over obstacles
- Connect samples to k-nearest neighbors
- Sample more points until qs and qg are connected

Searching in a Graph

- Generic
  - BFS (Breath First)
  - DFS (Depth First)
- Informed
  - “Heuristic” to guide the search

Take Away

- Families of approaches to navigate world
  - Reactive
    - Local area and fast response
  - Model-based
    - Big picture and long paths
    - Build and searching graphs