WPI

Planner for a 3D In-Hand Manipulation Platform on External Surfaces

RBE 598 Directed Research

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Introduction

Introduction

- Task of manipulating objects by hand without having to regrasp them or replace them on a surface
- Challenging in the sense that we have not been able to impart the same generalized skills to our robots
- Remains challenging, because it is still in its nascent stages, although helped by recent advances in deep learning and reinforcement learning

Previous Work

2D Planner

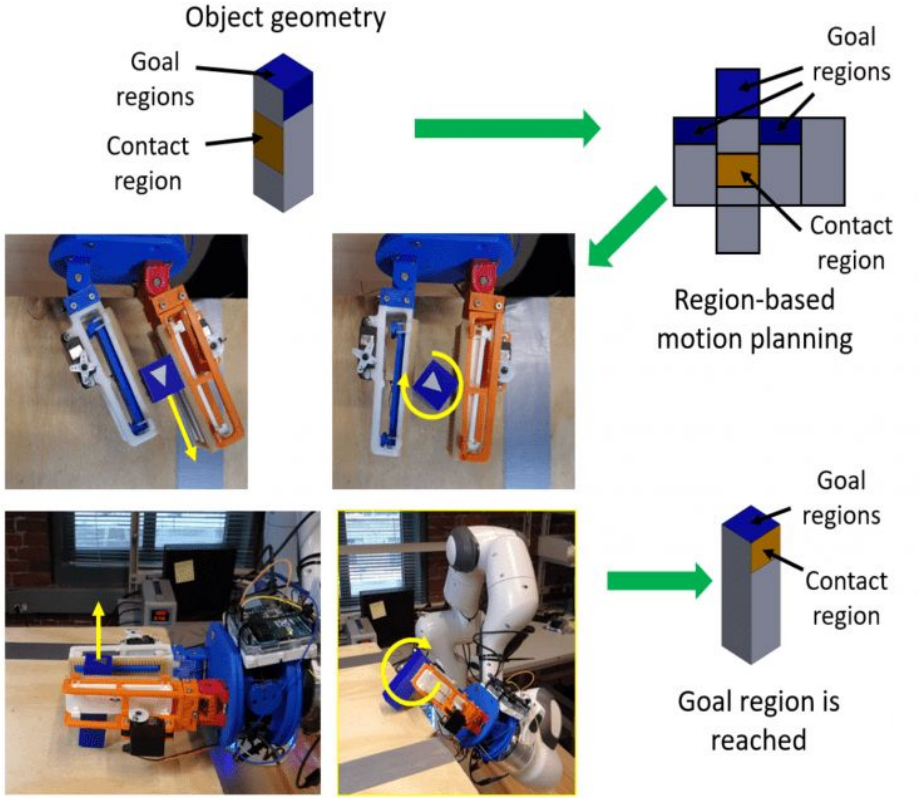
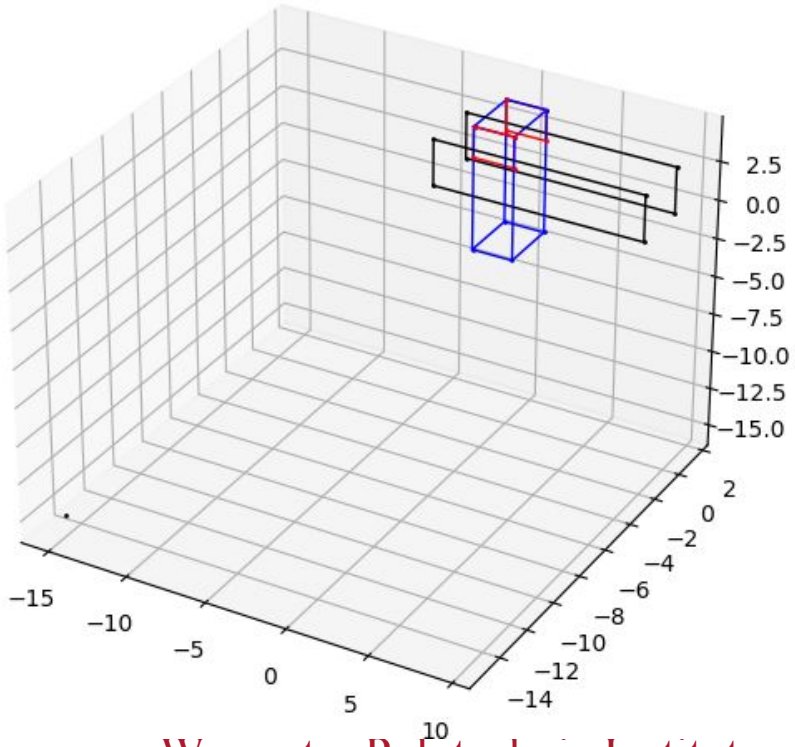


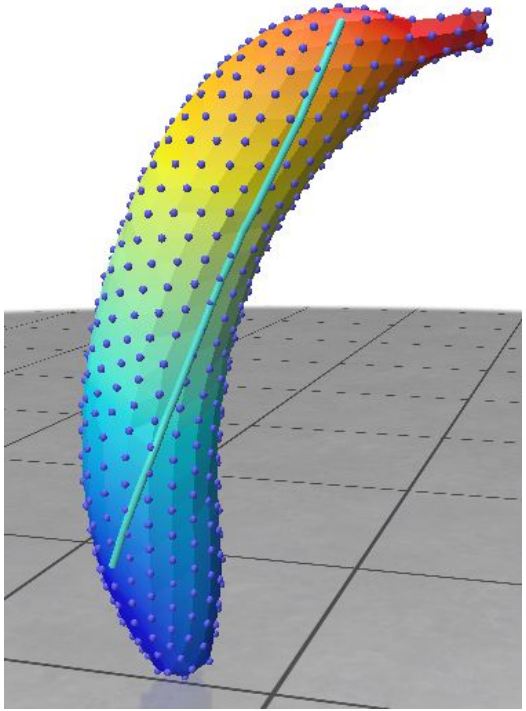
Image Courtesy: https://wp.wpi.edu/merlab/research/

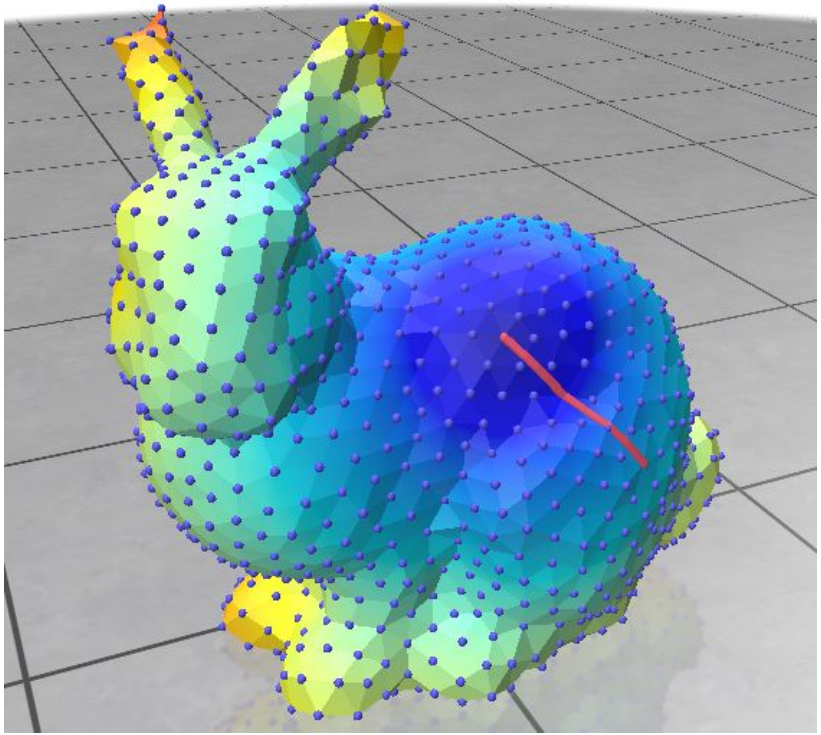
2D Planner

```
['Step', 'command']
[1, ('Move up', [1.5707963267948966, 1.5707963267948966, 0.5])]
[2, ('Move up', [1.5707963267948966, 1.5707963267948966, 0.5])]
[3, ('Move up', [1.5707963267948966, 1.5707963267948966, 0.5])]
[4, ('Slide left up', [1.4465680699691137, 1.5041487286580355])]
[5, ('Slide right up', [1.553568781085279, 1.612629585054675])]
[6, ('Slide right up', [1.638400306333383, 1.6927053898415487])]
[7, ('Slide left up', [1.5313042585399514, 1.5870595219897794])]
[8, ('Slide left up', [1.4509561702120166, 1.5023394298342965])]
[9, ('Slide left up', [1.3728258706267134, 1.4157831581088995])]
[10, ('Slide left up', [1.2961277027784415, 1.3269087374755575])]
[11, ('Slide left up', [1.220127585312978, 1.235162736205725])]
[12, ('Slide right up', [1.3092450395471675, 1.3404787129139923])]
[13, ('Slide right up', [1.3916734624386828, 1.4322079817329116])]
[14, ('Slide right up', [1.4742562405858302, 1.519375192517565])]
[15, ('Slide right up', [1.5575062464229206, 1.6030699097465788])]
[16, ('Pivot', [1.5575062464229206, 12.0, 1.5707963267948966, 2.5])]
```



Geodesic





Geodesic: Challenges

- Randomly generated point clouds/ID by meshing software
- Unable to link IDs with their coordinates
- Triangular meshed being generated, finger movement was difficult to implement

Goals

Goals

- Heuristic: Geodesic/Euclidean
- Define Pose
- More Efficient planner

Assumptions

Assumptions

a. Rectangular Prism

~~b. 4 actions (“UP”, “DOWN”, “ CW”, “CCW”)~~

~~c. Single Finger~~

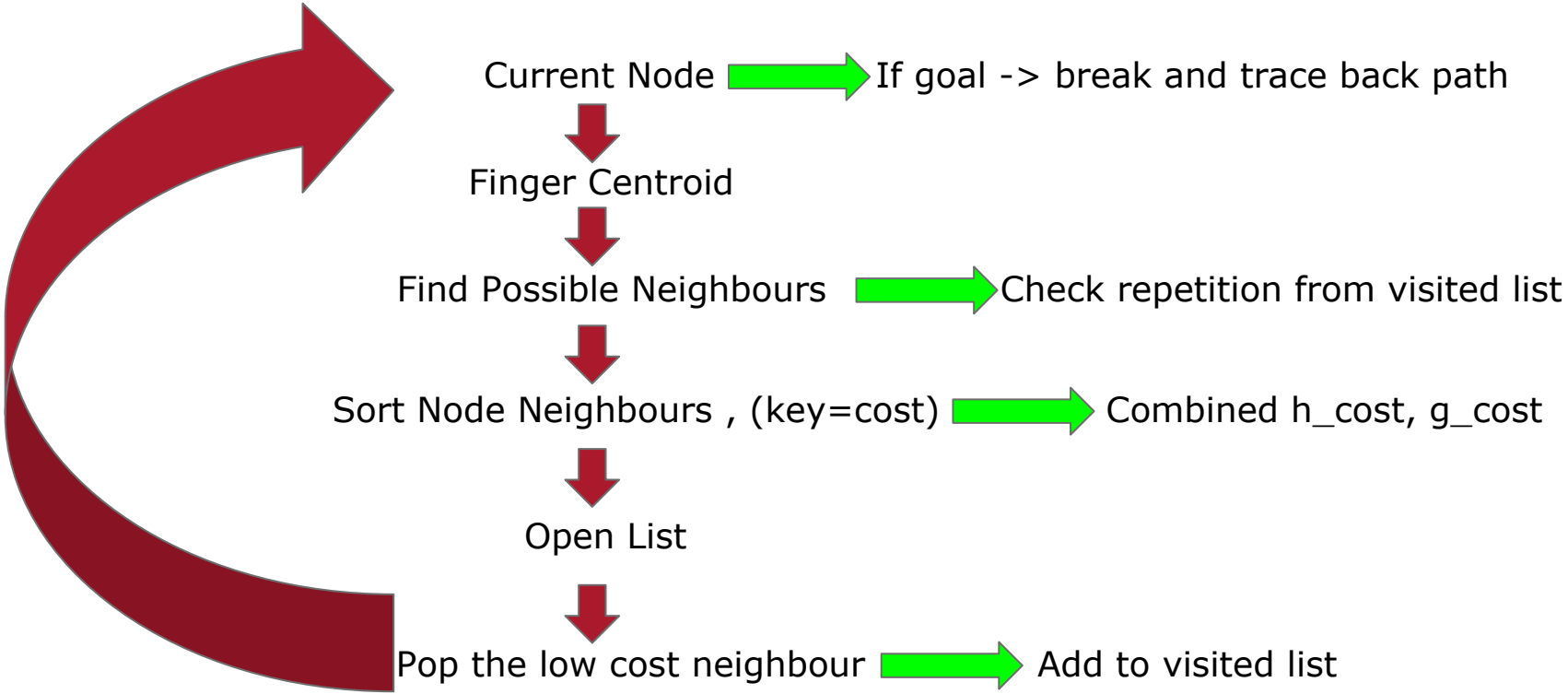
~~d. Only using 4 faces~~

e. 5 actions (“UP”, “DOWN”, “ CW”, “CCW”, “Pivot”)

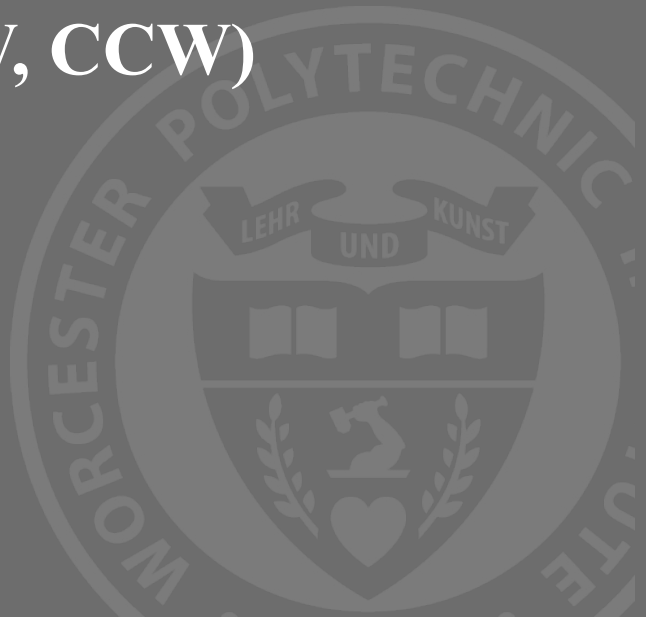
f. Currently assumes the center of the regions

Planner

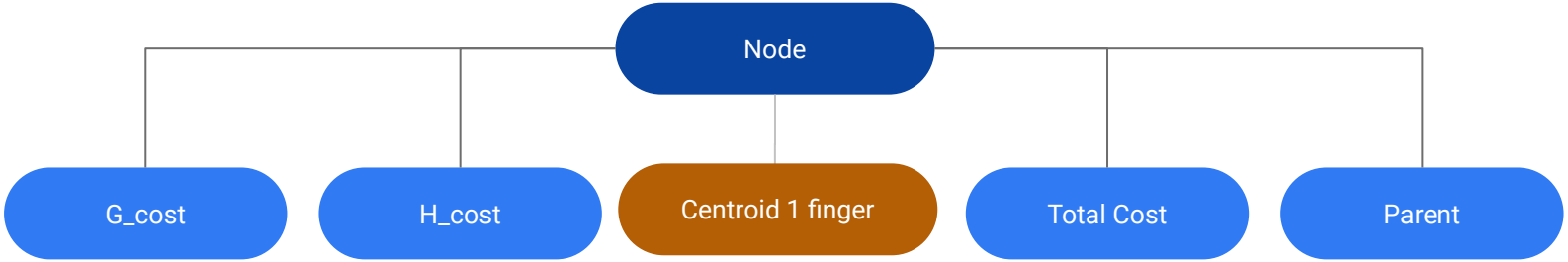
A* Planner

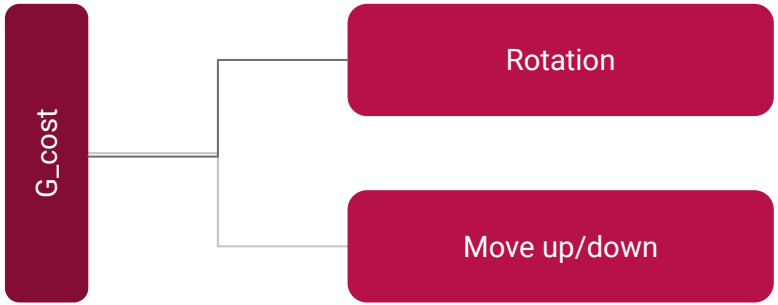

Current Node
If goal -> break and trace back path
Finger Centroid
Find Possible Neighbours
Check repetition from visited list
Sort Node Neighbours , (key=cost)
Combined h_cost, g_cost
Open List
Pop the low cost neighbour
Add to visited list

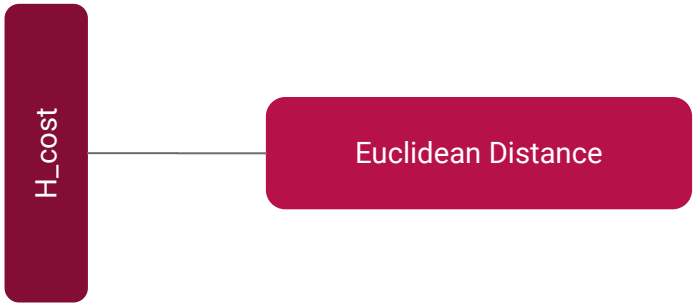
Basic Actions
(Up, Down, CW, CCW)



Node and Cost - One Finger

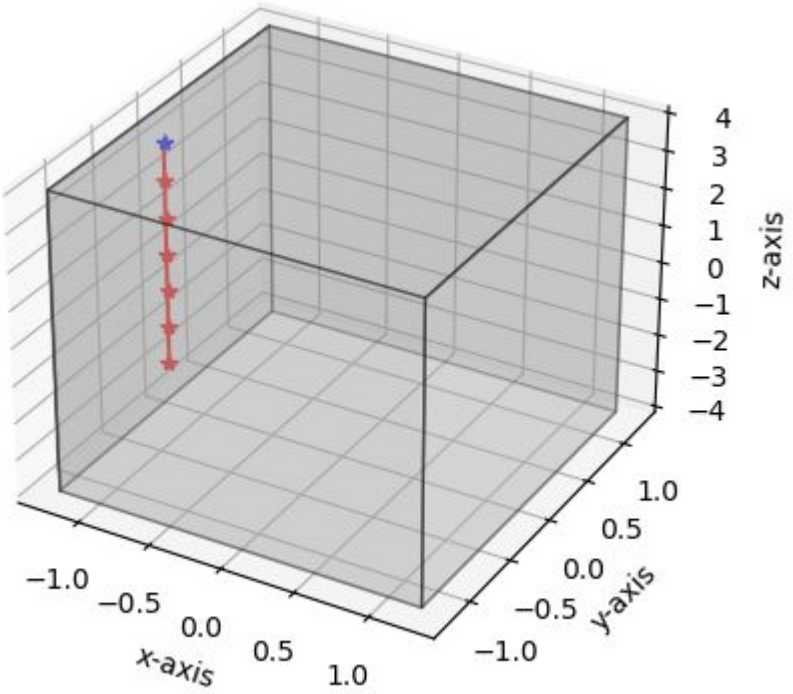






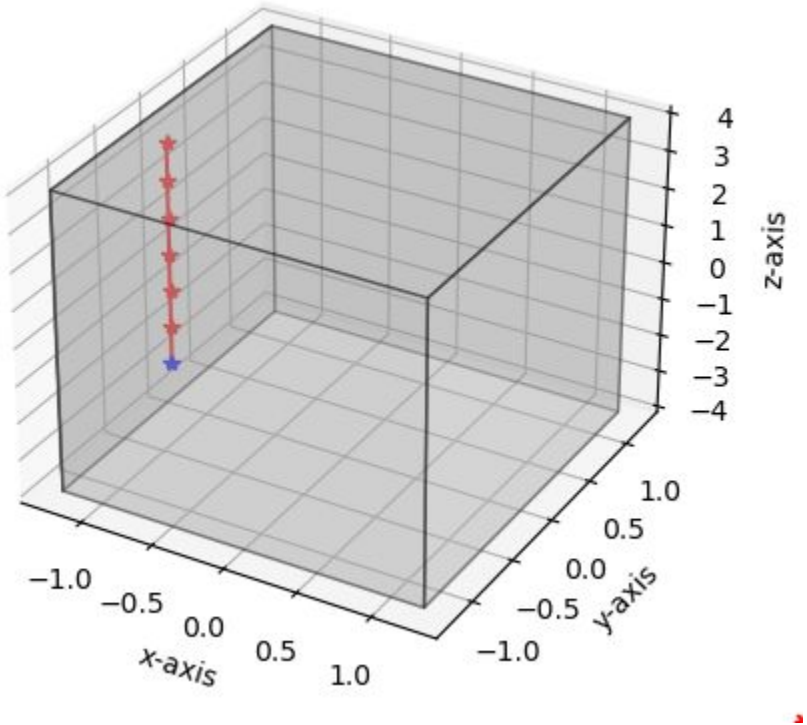
Centroid: Move Down

```
Start: (-1.25, 0, 3)  (BLUE marker)
Goal: (-1.25, 0, -3)
It takes 6 steps to find a path using A*
[[-1.25, 0, 3], 'Start']
[[-1.25, 0, 2], 'DOWN']
[[-1.25, 0, 1], 'DOWN']
[[-1.25, 0, 0], 'DOWN']
[[-1.25, 0, -1], 'DOWN']
[[-1.25, 0, -2], 'DOWN']
[[-1.25, 0, -3], 'DOWN']
```



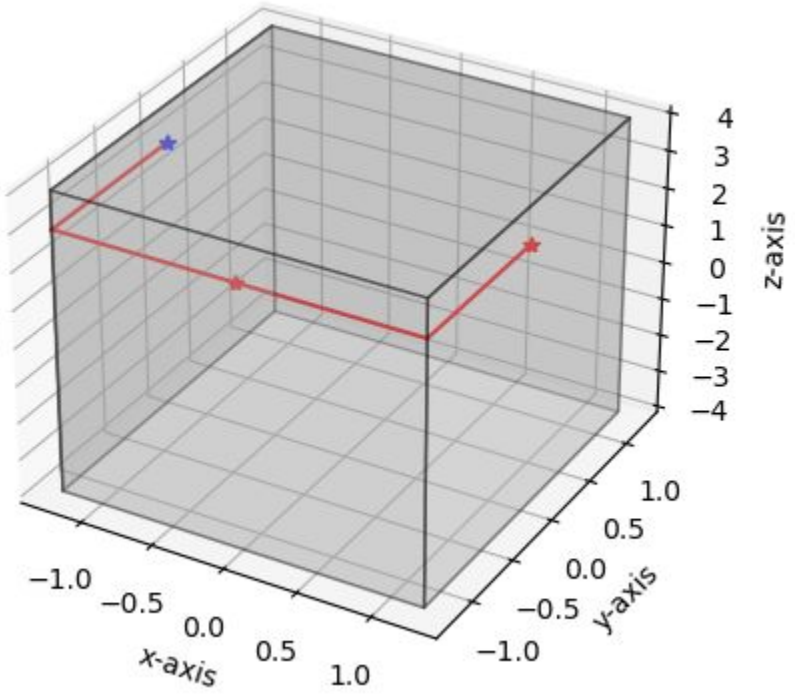
Centroid: Move Up

```
Start: (-1.25, 0, -3)  (BLUE marker)
Goal: (-1.25, 0, 3)
It takes 6 steps to find a path using A*
[[-1.25, 0, -3], 'Start']
[[-1.25, 0, -2], 'UP']
[[-1.25, 0, -1], 'UP']
[[-1.25, 0, 0], 'UP']
[[-1.25, 0, 1], 'UP']
[[-1.25, 0, 2], 'UP']
[[-1.25, 0, 3], 'UP']
```



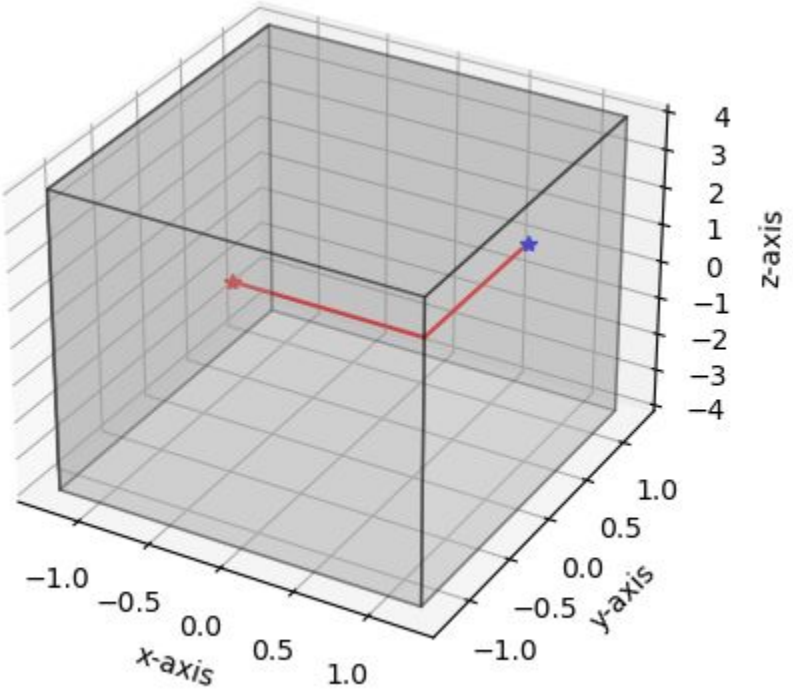
Centroid: Rotate Clockwise

```
Start: (-1.25, 0, 3)  (BLUE marker)
Goal: (1.25, 0, 3)
It takes 2 steps to find a path using A*
[[-1.25, 0, 3], 'Start']
[[0.0, -1.25, 3.0], 'CW']
[[1.25, 0.0, 3.0], 'CW']
```



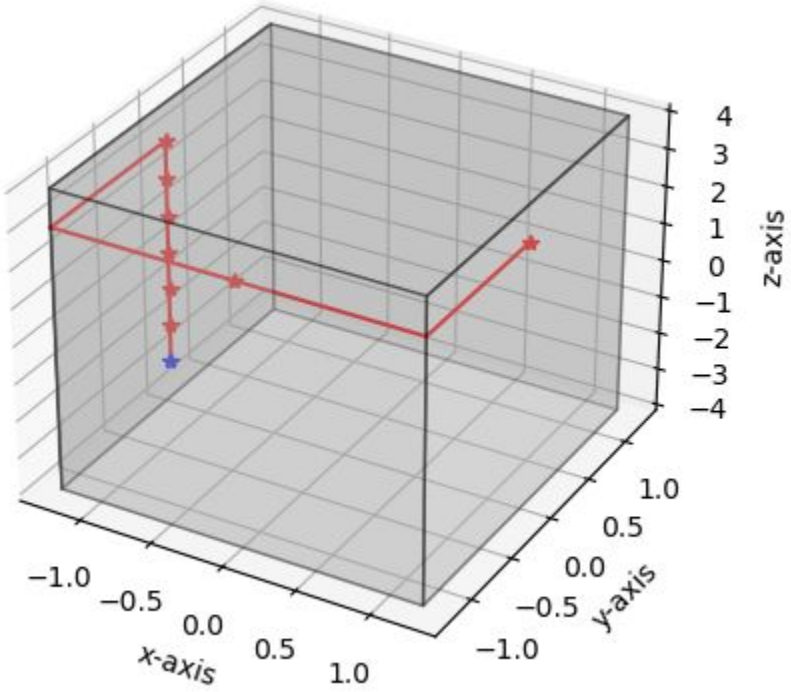
Centroid: Rotate Anti-Clockwise

```
Start: (1.25, 0, 3)  (BLUE marker)
Goal: (0, -1.25, 3)
It takes 1 steps to find a path using A*
[[1.25, 0, 3], 'Start']
[[0.0, -1.25, 3.0], 'CCW']
```



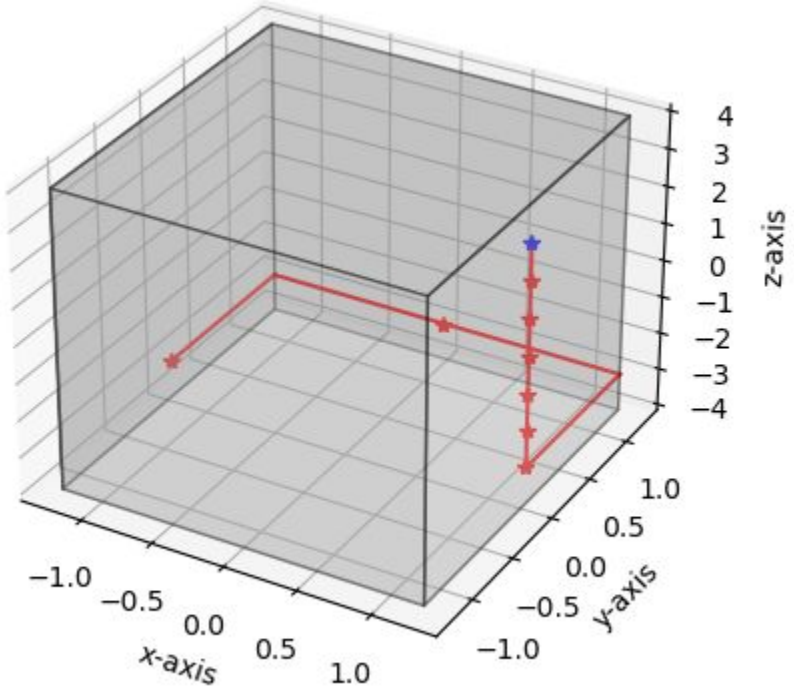
Centroid: Mixed Actions

```
Start: (-1.25, 0, -3)  (BLUE marker)
Goal: (1.25, 0, 3)
It takes 8 steps to find a path using A*
[[-1.25, 0, -3], 'Start']
[[-1.25, 0, -2], 'UP']
[[-1.25, 0, -1], 'UP']
[[-1.25, 0, 0], 'UP']
[[-1.25, 0, 1], 'UP']
[[-1.25, 0, 2], 'UP']
[[-1.25, 0, 3], 'UP']
[[0.0, -1.25, 3.0], 'CW']
[[1.25, 0.0, 3.0], 'CW']
```



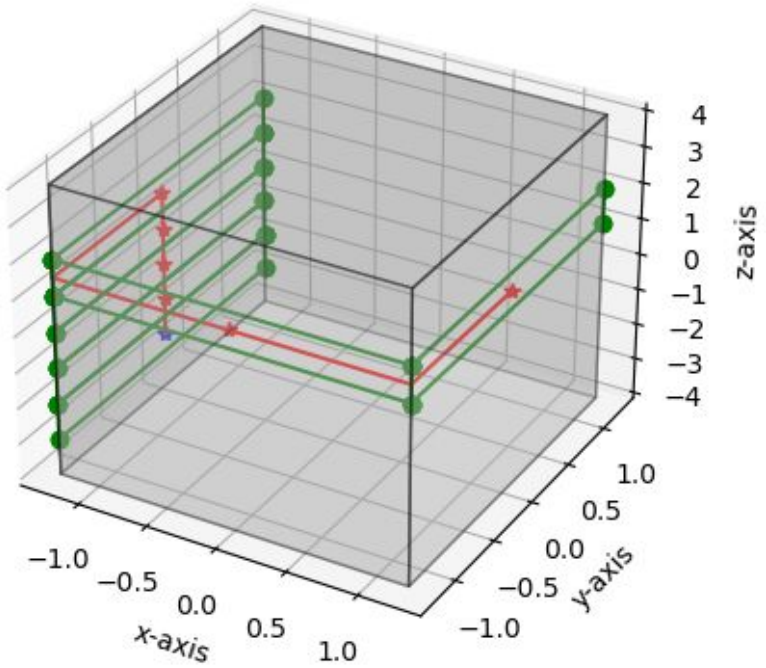
Centroid: Mixed Actions

```
Start: (1.25, 0, 3)  (BLUE marker)
Goal: (-1.25, 0, -3)
It takes 8 steps to find a path using A*
[[1.25, 0, 3], 'Start']
[[1.25, 0, 2], 'DOWN']
[[1.25, 0, 1], 'DOWN']
[[1.25, 0, 0], 'DOWN']
[[1.25, 0, -1], 'DOWN']
[[1.25, 0, -2], 'DOWN']
[[1.25, 0, -3], 'DOWN']
[[0.0, 1.25, -3.0], 'CW']
[[-1.25, 0.0, -3.0], 'CW']
```



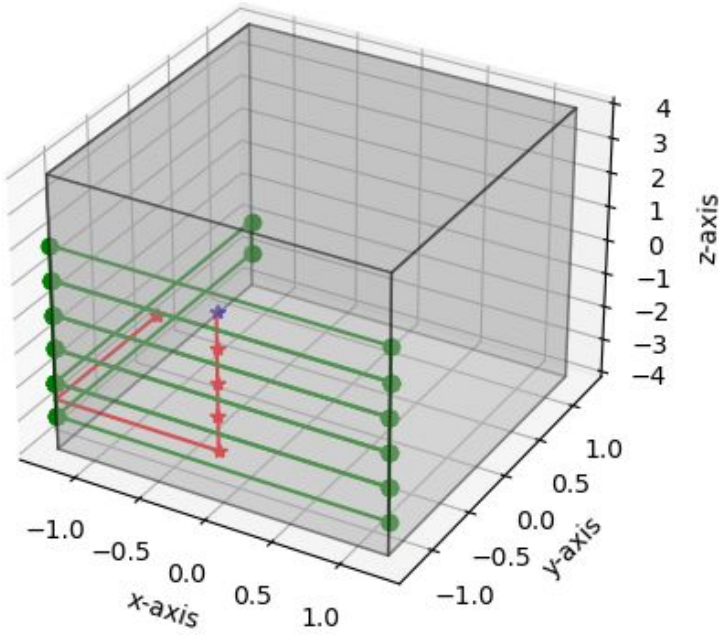
Area: Mixed Actions

```
Start Region: [(-1.25, -1.25, -3), (-1.25, -1.25, -2), (-1.25, 1.25, -2), (-1.25, 1.25, -3)]
Goal Region: [(1.25, -1.25, 2), (1.25, -1.25, 1), (1.25, 1.25, 1), (1.25, 1.25, 2)]
Start Centroid: (-1.25, 0.0, -2.5)  (BLUE marker)
Goal Centroid: (1.25, 0.0, 1.5)
It takes 6 steps to find a path using A*
Centroid Path 0: [[-1.25, 0.0, -2.5], 'Start']
Centroid Path 1: [[-1.25, 0.0, -1.5], 'UP']
Centroid Path 2: [[-1.25, 0.0, -0.5], 'UP']
Centroid Path 3: [[-1.25, 0.0, 0.5], 'UP']
Centroid Path 4: [[-1.25, 0.0, 1.5], 'UP']
Centroid Path 5: [[0.0, -1.25, 1.5], 'CW']
Centroid Path 6: [[1.25, 0.0, 1.5], 'CW']
Reg Points 0: [(-1.25, -1.25, -3), (-1.25, -1.25, -2), (-1.25, 1.25, -2), (-1.25, 1.25, -3)]
Reg Points 1: [(-1.25, -1.25, -2), (-1.25, -1.25, -1), (-1.25, 1.25, -1), (-1.25, 1.25, -2)]
Reg Points 2: [(-1.25, -1.25, -1), (-1.25, -1.25, 0), (-1.25, 1.25, 0), (-1.25, 1.25, -1)]
Reg Points 3: [(-1.25, -1.25, 0), (-1.25, -1.25, 1), (-1.25, 1.25, 1), (-1.25, 1.25, 0)]
Reg Points 4: [(-1.25, -1.25, 1), (-1.25, -1.25, 2), (-1.25, 1.25, 2), (-1.25, 1.25, 1)]
Reg Points 5: [(1.25, -1.25, 1.0), (1.25, -1.25, 2.0), (-1.25, -1.25, 2.0), (-1.25, -1.25, 1.0)]
Reg Points 6: [(1.25, 1.25, 1.0), (1.25, 1.25, 2.0), (1.25, -1.25, 2.0), (1.25, -1.25, 1.0)]
```



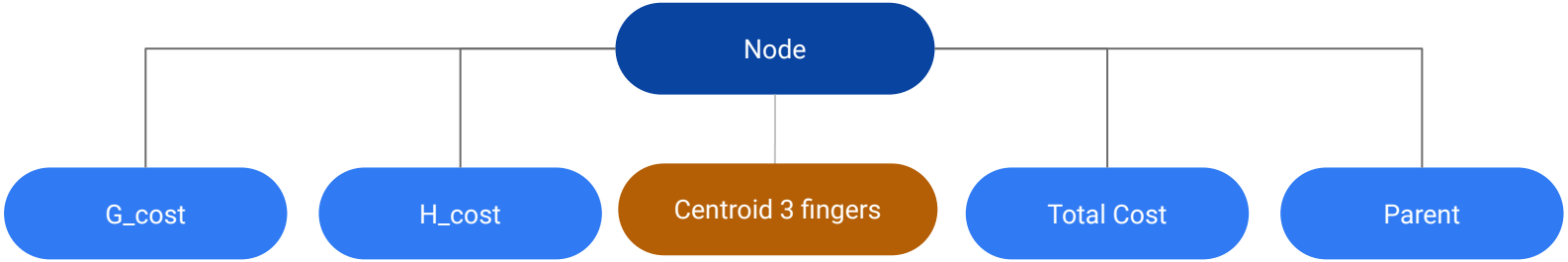
Area: Mixed Actions

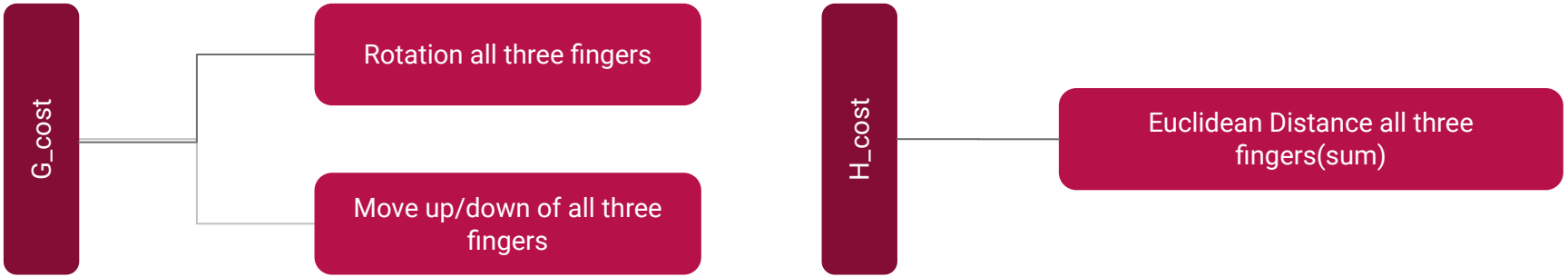
```
Start Region: [(1.25, -1.25, 2), (1.25, -1.25, 1), (-1.25, -1.25, 1), (-1.25, -1.25, 2)]
Goal Region: [(-1.25, -1.25, -3), (-1.25, -1.25, -2), (-1.25, 1.25, -2), (-1.25, 1.25, -3)]
Start Centroid: (0.0, -1.25, 1.5)  (BLUE marker)
Goal Centroid: (-1.25, 0.0, -2.5)
It takes 5 steps to find a path using A*
Centroid Path 0: [[0.0, -1.25, 1.5], 'Start']
Centroid Path 1: [[0.0, -1.25, 0.5], 'DOWN']
Centroid Path 2: [[0.0, -1.25, -0.5], 'DOWN']
Centroid Path 3: [[0.0, -1.25, -1.5], 'DOWN']
Centroid Path 4: [[0.0, -1.25, -2.5], 'DOWN']
Centroid Path 5: [[-1.25, 0.0, -2.5], 'CCW']
Reg Points 0: [(1.25, -1.25, 2), (1.25, -1.25, 1), (-1.25, -1.25, 1), (-1.25, -1.25, 2)]
Reg Points 1: [(1.25, -1.25, 1), (1.25, -1.25, 0), (-1.25, -1.25, 0), (-1.25, -1.25, 1)]
Reg Points 2: [(1.25, -1.25, 0), (1.25, -1.25, -1), (-1.25, -1.25, -1), (-1.25, -1.25, 0)]
Reg Points 3: [(1.25, -1.25, -1), (1.25, -1.25, -2), (-1.25, -1.25, -2), (-1.25, -1.25, -1)]
Reg Points 4: [(1.25, -1.25, -2), (1.25, -1.25, -3), (-1.25, -1.25, -3), (-1.25, -1.25, -2)]
Reg Points 5: [(-1.25, -1.25, -2.0), (-1.25, -1.25, -3.0), (-1.25, 1.25, -3.0), (-1.25, 1.25,
```



Finger Shadow

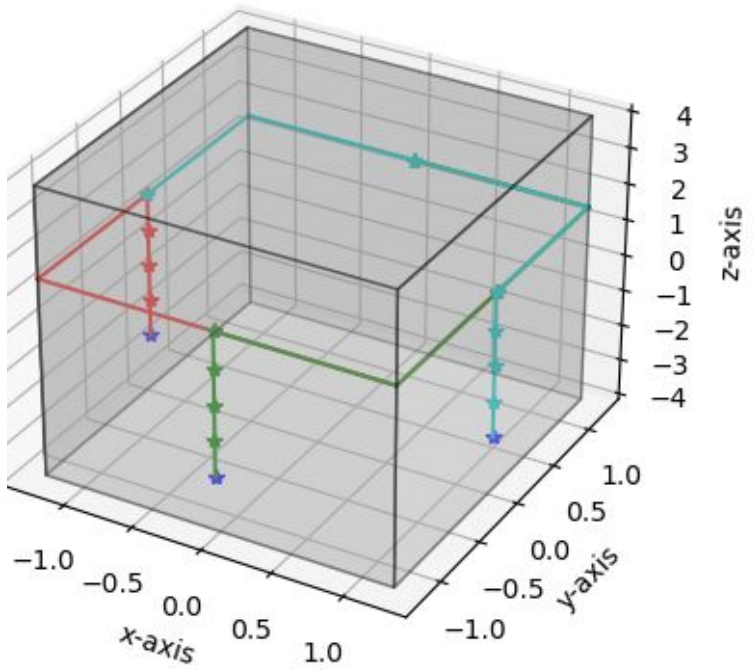
Node and Cost - Three point





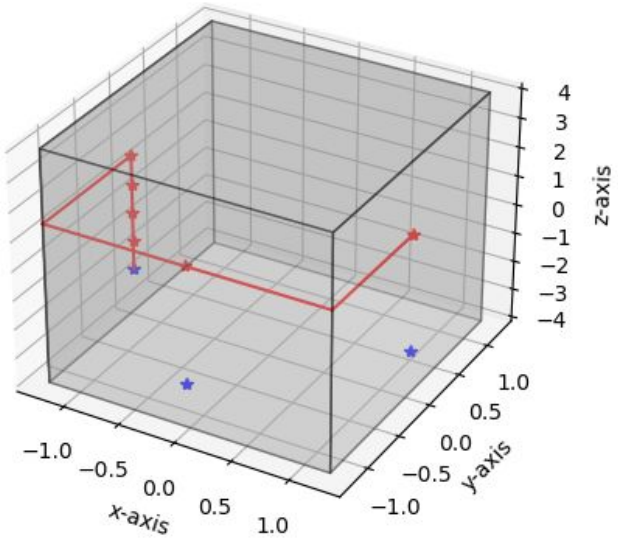
Results

```
start:(in blue *)
 [[-1.25  0.   -2.5 ]
 [ 0.   -1.25 -2.5 ]
 [ 1.25  0.   -2.5 ]]
goal:
 [[ 1.25  0.    1.5 ]
 [ 0.    1.25  1.5 ]
 [-1.25  0.    1.5 ]]


path: ['UP', 'UP', 'UP', 'UP', 'CW', 'CW']


Centroid Path: 'r', 'g', 'c'
Centroid Path 1: [-1.25, 0.0, -1.5] [0.0, -1.25, -1.5] [1.25, 0.0, -1.5]
Centroid Path 2: [-1.25, 0.0, -0.5] [0.0, -1.25, -0.5] [1.25, 0.0, -0.5]
Centroid Path 3: [-1.25, 0.0, 0.5] [0.0, -1.25, 0.5] [1.25, 0.0, 0.5]
Centroid Path 4: [-1.25, 0.0, 1.5] [0.0, -1.25, 1.5] [1.25, 0.0, 1.5]
Centroid Path 5: [ 0.   -1.25  1.5 ] [1.25 0.   1.5 ] [0.   1.25 1.5 ]
Centroid Path 6: [1.25 0.   1.5 ] [0.   1.25 1.5 ] [-1.25  0.    1.5 ]
```

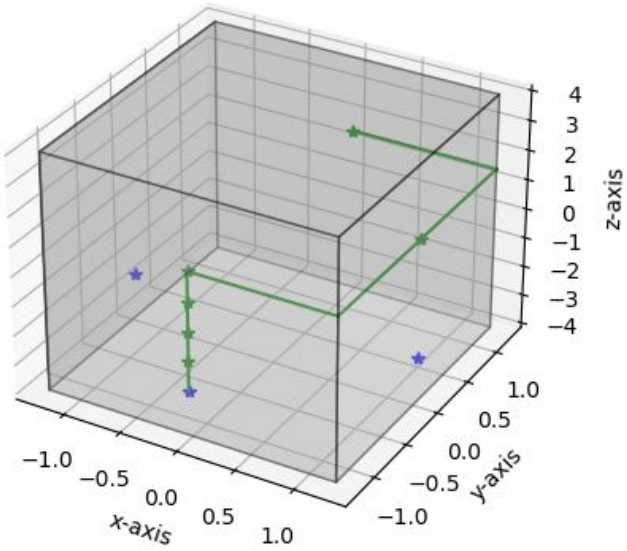


Results

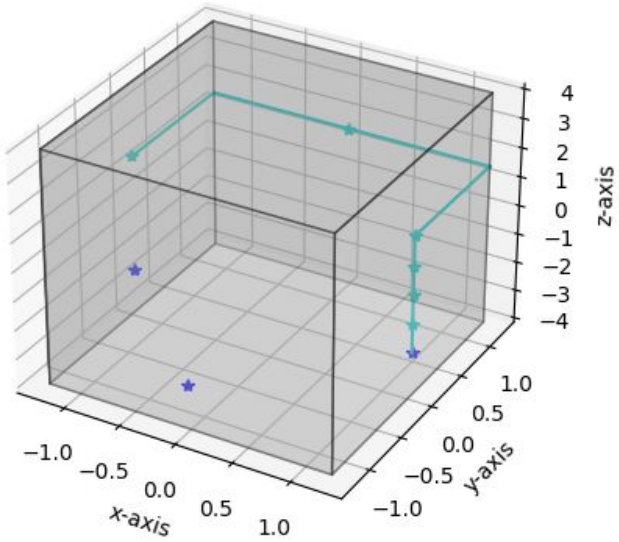
Left



Shadow

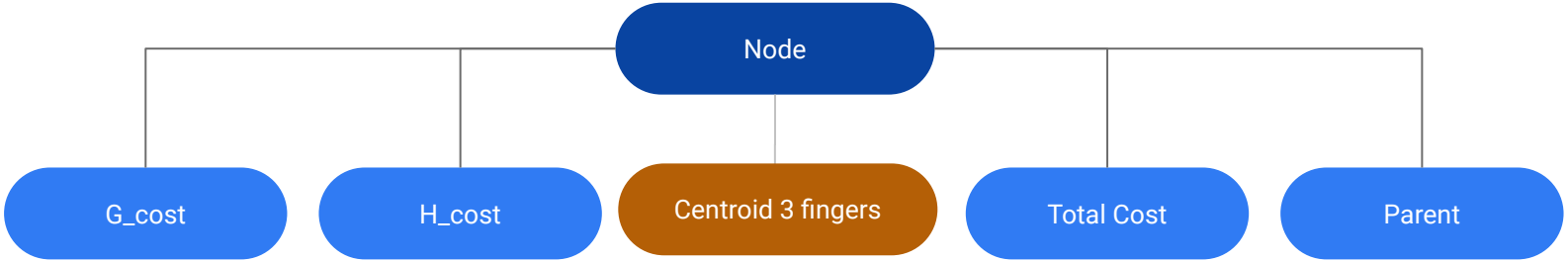


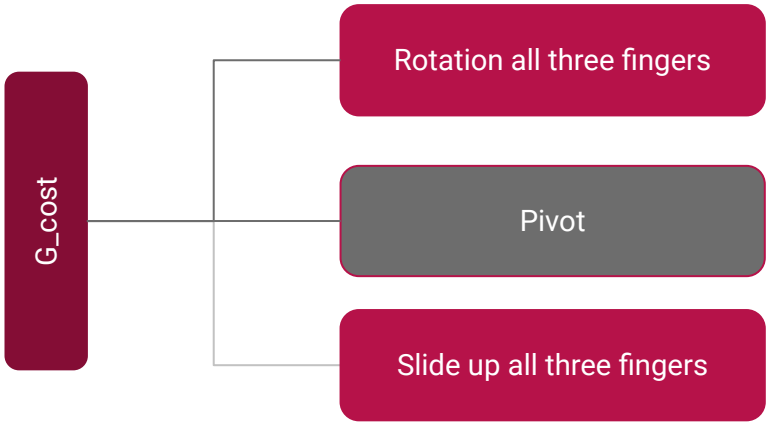
Right



Pivot

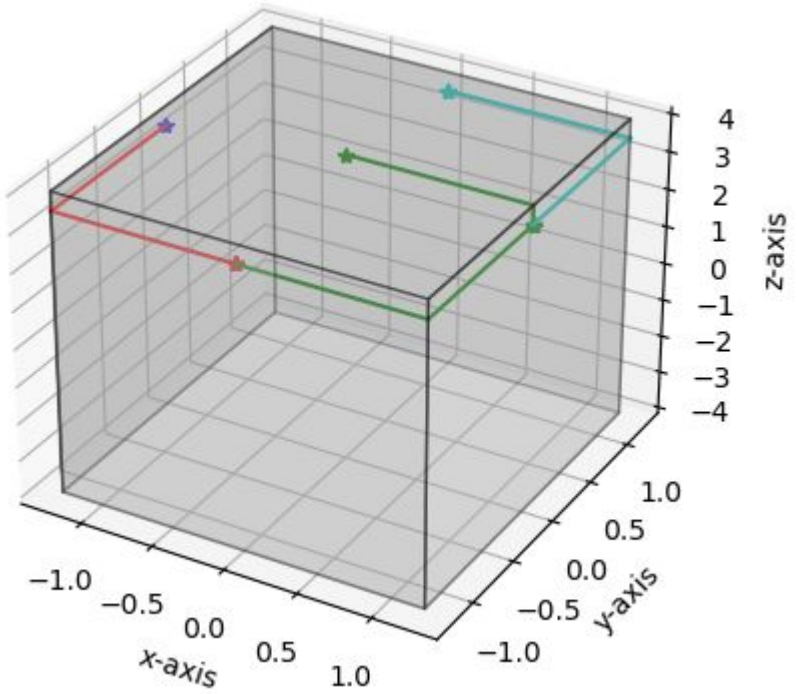
Node and Cost - Three point (Pivot)



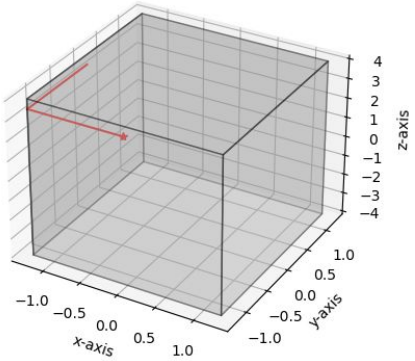
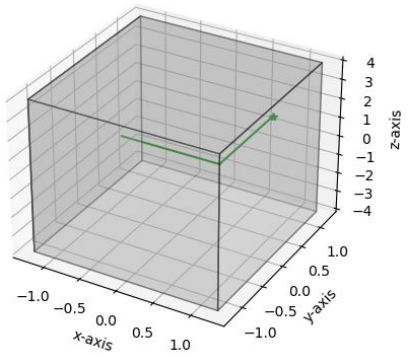
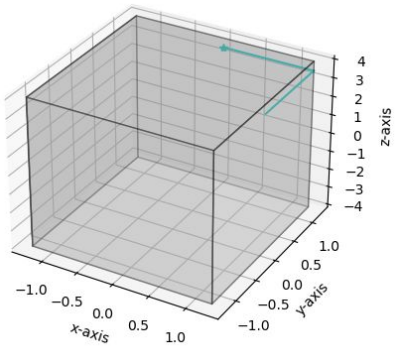
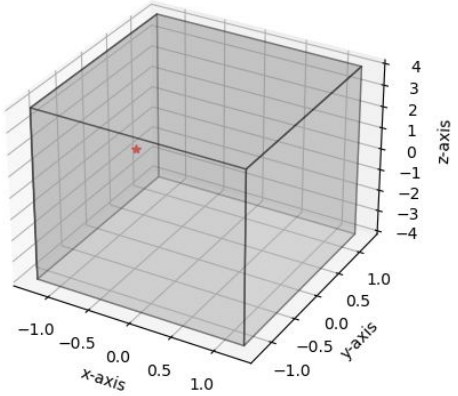
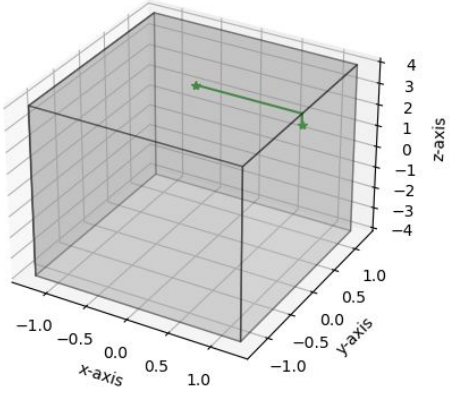
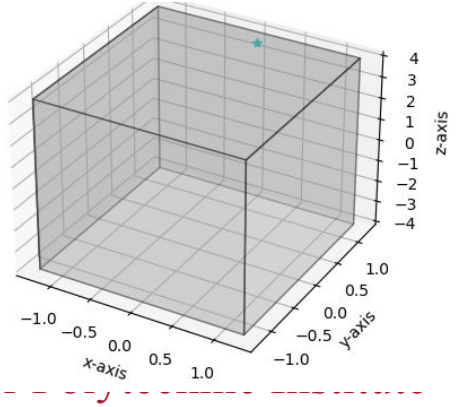


Results

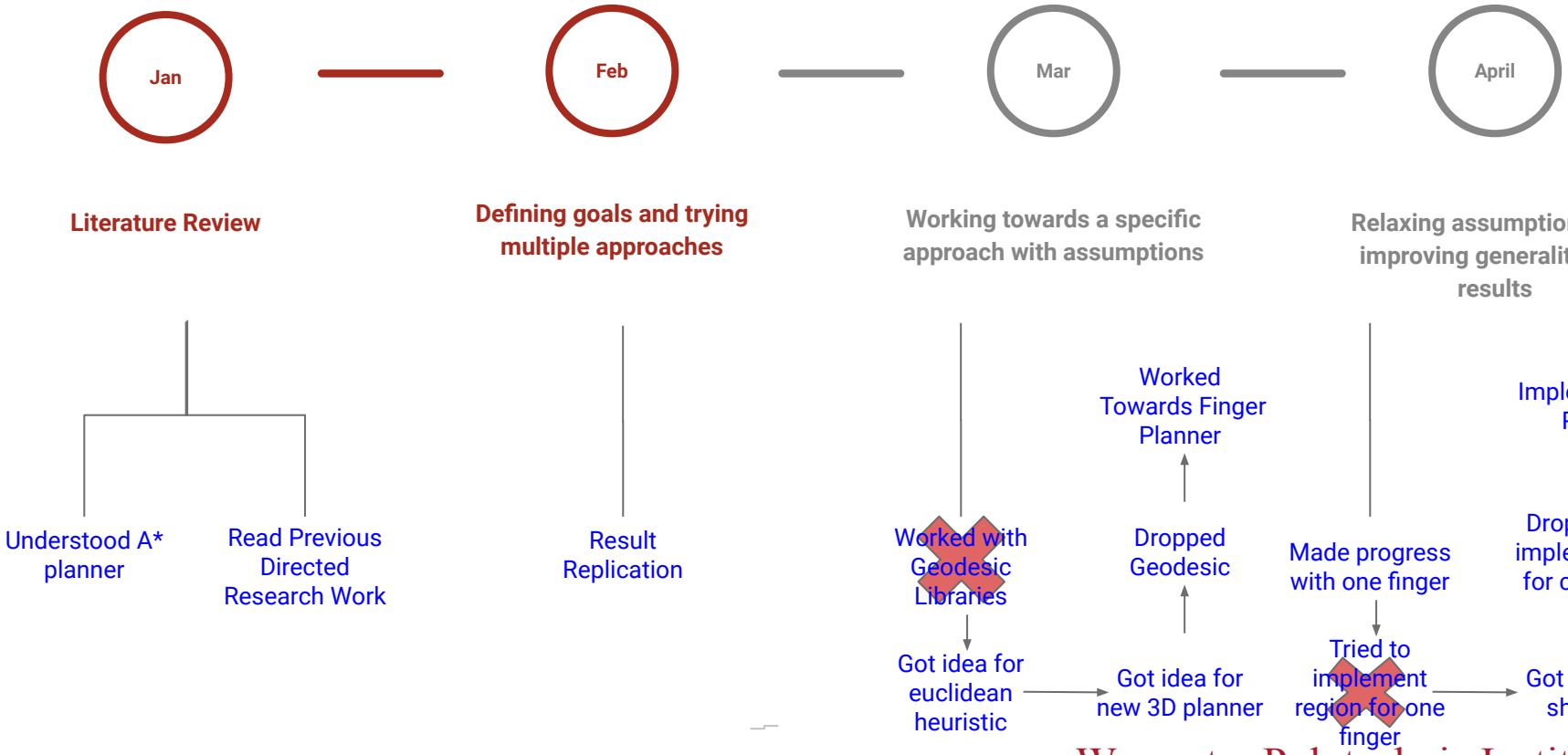
```
start:
 [[-1.25  0.    3.5 ]
 [ 0.   -1.25  3.5 ]
 [ 1.25  0.    3.5 ]]
goal:
 [[ 0.   -1.25  3.5 ]
 [ 0.    0.    4.  ]
 [ 0.    1.25  3.5 ]]


actions: ['CW', 'PVT']


path:
[0.0, -1.25, 3.5] [1.25, 0.0, 3.5] [0.0, 1.25, 3.5]
[0, -1.25, 3.5] [0, 0, 4.0] [0, 1.25, 3.5]
```



Results

	Left	Shadow	Right
Step 1: "CW"			
Step 2: "Pivot"			

Research Journey



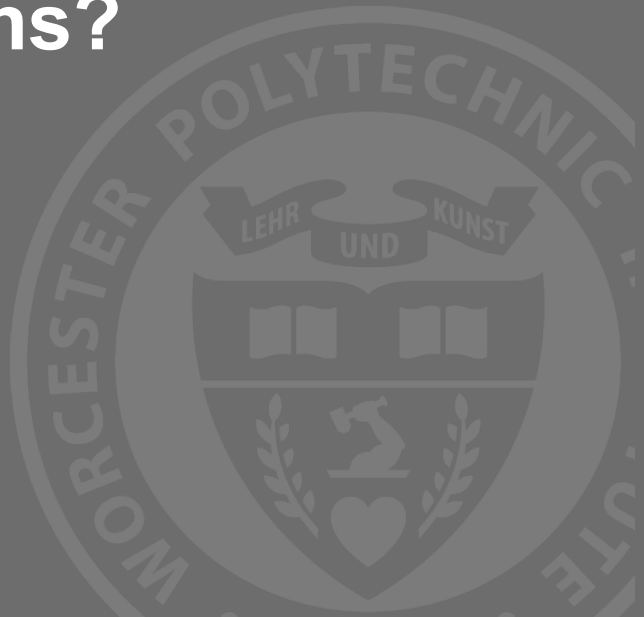
Future Possibilities

Created a base of future implementations:

a. Geodesic Heuristic
b. Actions: Sliding can be included
c. Multiple geometries (symmetric, unsymmetric), etc.
d. Currently exact goal area, Region-Based
e. Needs to be tested on hardware
f. Closing the open loop

Thank you!

Any Questions?



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