On Use of Nav2 Smac Planners

Steve Macenski, Samsung Research America

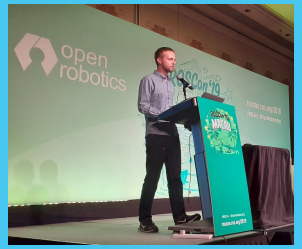
Steve Macenski

Senior Technical Lead - Samsung Research

- Your Friendly Neighborhood Navigator!
- ROS Technical Steering Committee Member
- Navigation Working Group & Project Lead
- Developed 50+ ROS & ROS 2 Packages

NASA Goddard (2015 - 2017)

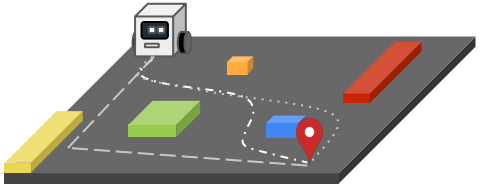
Simbe Robotics (2017 - 2019)



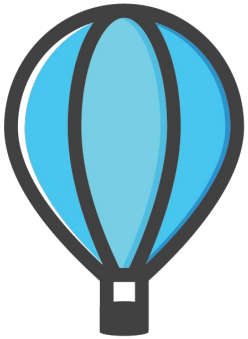
Samsung Research America (2019 - Present)

Overview

Background



Nav2 Smac Planners



In The Wild

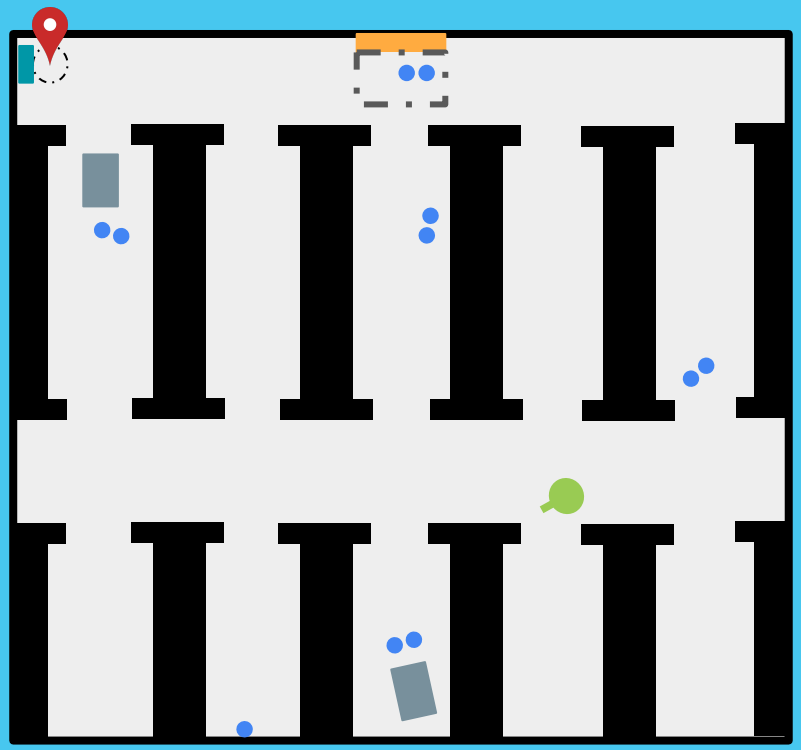
Background - Path Planning

“How Do I Get There?”

Finding a route through an environment
- Could be **feasible**, but not definitionally
- Could be a **trajectory**, but not definitionally

Paired with a Local Trajectory Planner
- Costly traj. planning locally
- Path / route planning globally

When is it ***not*** needed?
- Predefined routes or ‘teach and repeat’
- Simplistic environments / following tasks



Background - Path Planning

Major Classes of Path Planners

Search

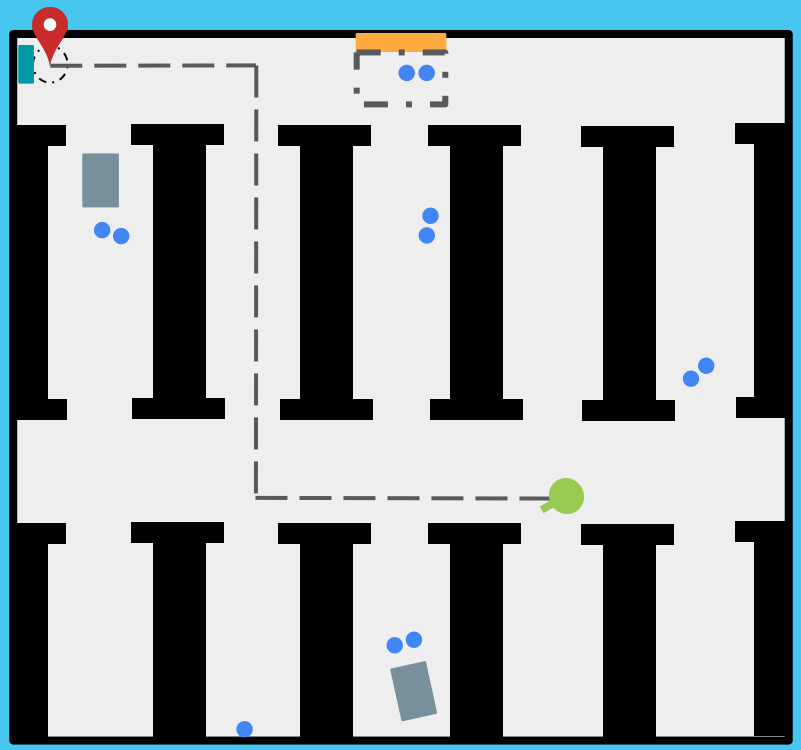
- Dijkstra's, A*, State Lattice, SBPL

Sampling

- RRT & Variants, OMPL

Optimization and Smoothing

- Gradient Descent on Objective Functions



Background - Path Planning

Major Classes of Path Planners

Search
- Dijkstra's, A*, State Lattice, SBPL

Sampling
- RRT & Variants, OMPL

Optimization and Smoothing
- Gradient Descent on Objective Functions

* Admittedly, this is a bit of a strawman example, but we only have 15 min!

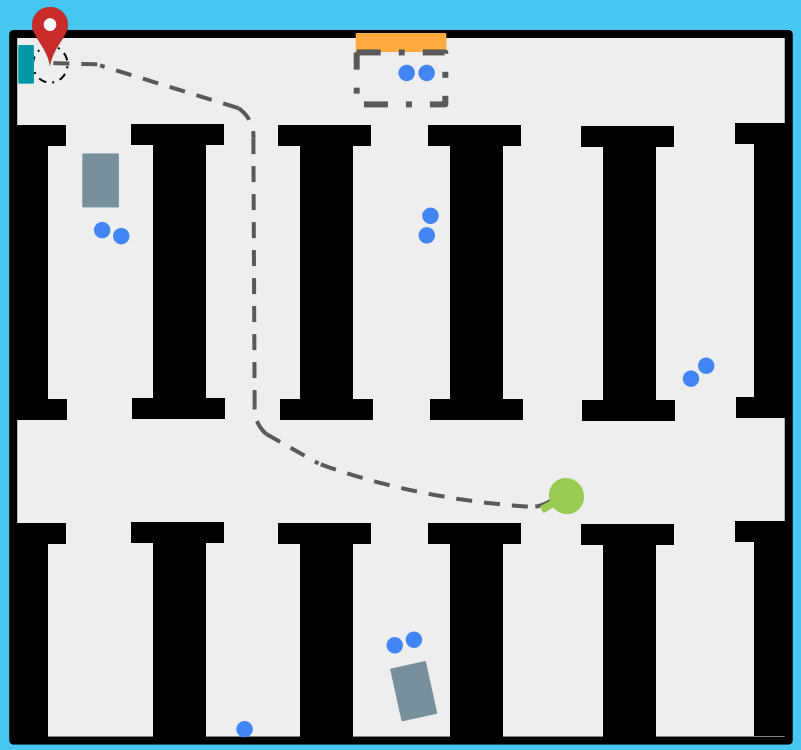
Background - Path Planning

Major Classes of Path Planners

Search
- Dijkstra's, A*, State Lattice, SBPL

Sampling
- RRT & Variants, OMPL

Optimization and Smoothing
- Gradient Descent on Objective Functions



Background - ROS Planning

What Options Did We Have in ROS (1)?

Navigation Stack
- NavFn
- Global Planner

The Community
- DLux Global Planner
- Voronoi Planner
- SBPL Lattice Planner

→ Plenty of circular diff and omni options

Background - ROS Planning

What Options Did We Have in ROS (1)?

Navigation Stack
- NavFn
- Global Planner

The Community
- DLux Global Planner
- Voronoi Planner
- SBPL Lattice Planner

→ Plenty of circular diff and omni options

No teach & repeat or pre-defined route following?
(though not the topic of today's talk)

Background - ROS Planning

What Options Did We Have in ROS (1)?

Navigation Stack
- NavFn
- Global Planner

The Community
- DLux Global Planner
- Voronoi Planner
- SBPL Lattice Planner

→ Plenty of circular diff and omni options

No teach & repeat or pre-defined route following?
(though not the topic of today's talk)

Where's the support for non-circular robots?

Background - ROS Planning

What Options Did We Have in ROS (1)?

Navigation Stack
- NavFn
- Global Planner

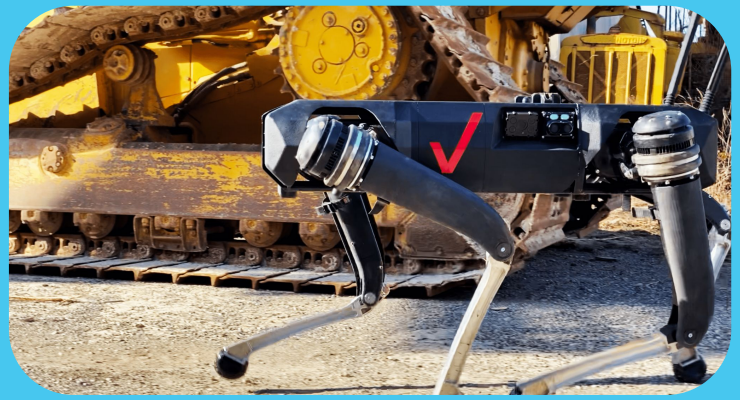
The Community
- DLux Global Planner
- Voronoi Planner
- SBPL Lattice Planner

→ Plenty of circular diff and omni options

No teach & repeat or pre-defined route following?
(though not the topic of today's talk)

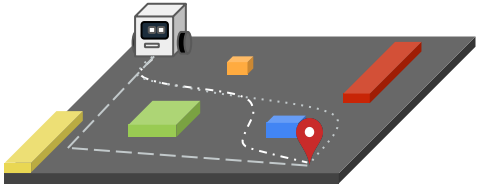
Where's the support for non-circular robots?

What about Ackermann or Legged robots?

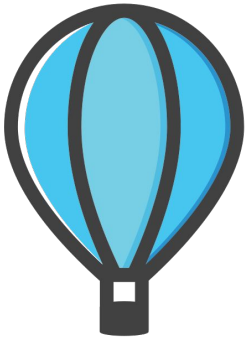


Overview

Background



Nav2 Smac Planners



In The Wild

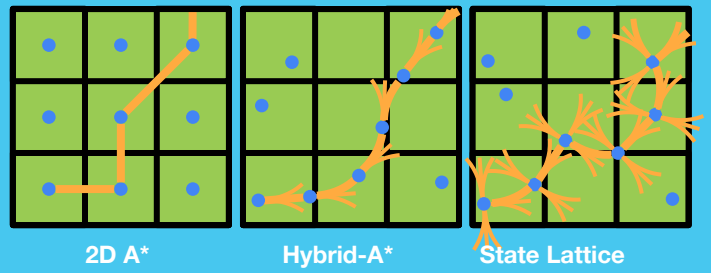
Smac Planner - Overview

Cost-Aware A*-Based Planning Framework

- Feature-Packed Templated A* Search Algorithm
- Multiple Node Types, Creating 3 Unique Planners
  More can be added!
- Enables Non-Circular, Legged, Ackermann, Diff & Omni
- Optimized for High Performance; Drop-In Replacement
- 93% Unit Test Coverage, Used in Production Today

```
SmacAStar<NodeT>

while not queue.empty()
  node = getNextNode()

  if node->wasVisited()
    continue
  node->visited()

  node = tryAnalyticExpansion(node)

  if isGoal(node) or withinApproachTol(node)
    return backtrace(node)

  for neighbor in node->getNeighbors()
    g = node->getAccumulatedCost() + node->getTraversalCost()
    if g < neighbor->getAccumulatedCost()
      neighbor->setAccumulatedCost(g)
      neighbor->parent = node
      addNode(g + neighbor->getHeuristicCost(), neighbor)
```

```
NodeT
                getAccumulate
dCost()
setAccumulatedCost(...)

visited()
wasVisited()

getTraversalCost(...)
getHeuristicCost(...)
getNeighbors(...)
                ...
```



Smac Planner - Need

Support for New / Modern Robot Types

Alternative for Circular or Small Robots *(2D)*

Non-Circular or Large Diff / Omni *(Lattice / Hybrid)*

- Where a circular assumption is not possible

Legged or Ackermann *(Lattice / Hybrid)*

- Curvature constrained, kinematically feasible
- Arbitrary models for bespoke systems

Nav2 Supports All Major Robot Types

	Available in ROS			Available in ROS 2			
	Global Planner	DLux Planner	NavFn	Theta*	Smac 2D	Smac Hybrid	Smac Lattice
Circular Differential	✓	✓	✓	✓	✓	✓	
Non-Circular Differential						✓	✓
Circular Omni	✓	✓	✓	✓	✓		
Non-Circular Omni							✓
Ackermann (All)						✓	✓
Legged (All)						✓	✓

Planning Algorithm's Best Usage Guide

Smac Planner - Some Important Technical Deets

Cost-Aware Obstacle Heuristic

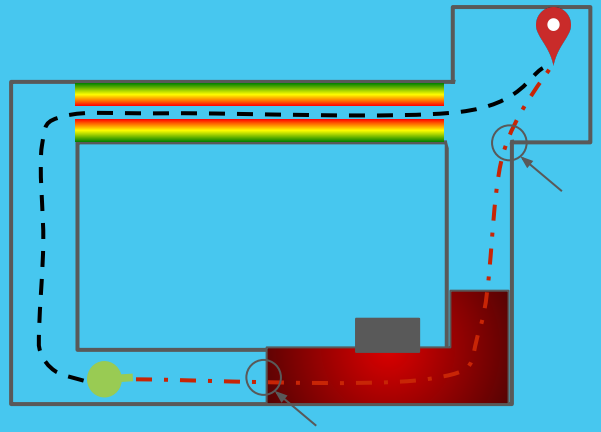
- Steers towards solution, away from obstacles
- Uses cost, not just binary obstacles
- Respect user behavioral constraints
- Higher quality path before smoothing

Search Penalty Functions

- Reverse, Change Direction, Non-Straight, Cost

Analytic Expansions

- Finds exact & feasible paths to the goal



Smac Planner - 2D A*

Circular Diff / Omni

Performance: **20 - 200 ms**

Simple Grid-A* with Smoothing

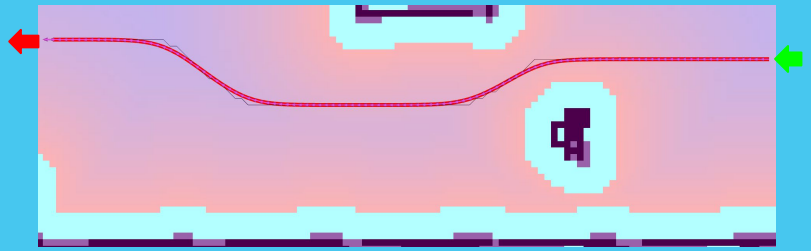
Point-Cost Collision Checking

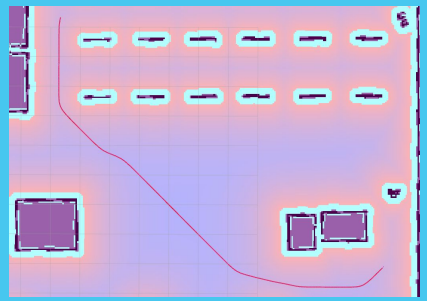
Moore Search Model

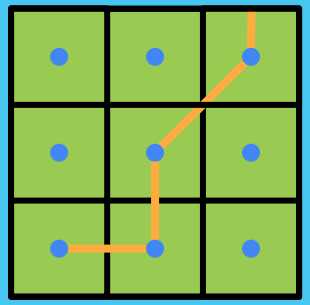
L2 Distance Heuristic

Consistent Behavior in Heterogeneous Fleet

$$cost_{trav.} = L_{prim} * (1 + \frac{w_{cost} * cost_{i,j}}{cost_{max}})$$







2D-A*

Hybrid-A*

State Lattice

Smac Planner - Hybrid-A*

Ackermann, Legged

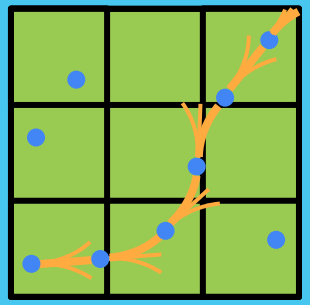
Performance: **20 - 60 ms**

SE2 Pose Collision Checking

Kinematically Feasible

Dubins or Reed-Shepp Search Model
- Dynamically adjusted
- + Analytic Expansions

Heuristic is the Maximum of:
- Precomputed Kine-Distance Window
- Cost-Aware Obstacle Heuristic



2D-A*

Hybrid-A*

State Lattice

Smac Planner - State Lattice

Non-Circular Diff / Omni, Arbitrary

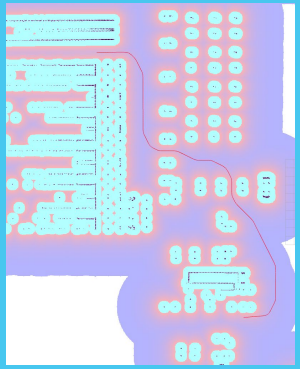
Performance: **30 - 65 ms**

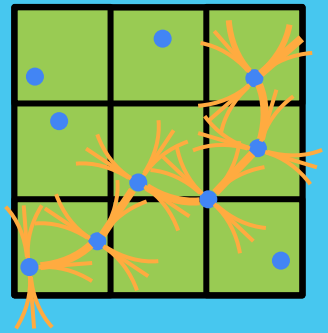
SE2 Pose Collision Checking

Kinematically Feasible

Minimum Control Set Search Model
- Generated offline
- + Analytic Expansions

Heuristic is the Maximum of:
- Precomputed Kine-Distance Window
- Cost-Aware Obstacle Heuristic





2D-A*

Hybrid-A*

State Lattice

Smac Planner - State Lattice - Generator

Minimum Control Set Generator

Creates set of primitives to describe motion model

- In a structured & principled lattice pattern
- Primitives smoothly transition from one to another

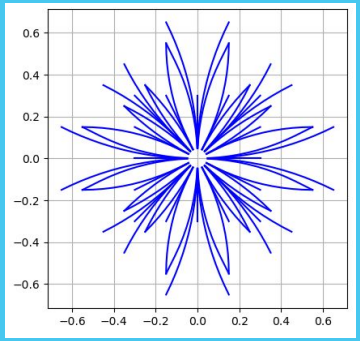
For each cell + heading in a wavefront:

→ Create a curvature minimizing trajectory

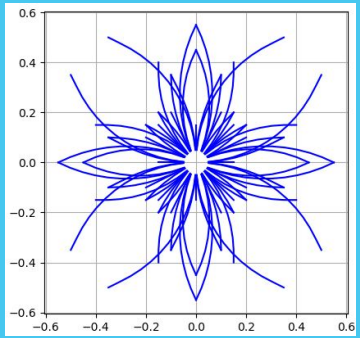
→ Check if a similar traj. can be constructed from set

→ If not, add it to the set

Repeat until a wavefront adds no new primitives



1.0m turning radius



0.5m turning radius

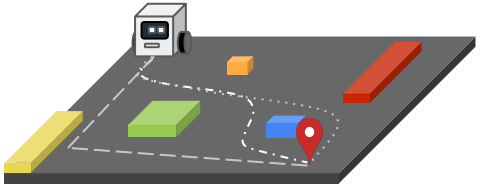
2D-A*

Hybrid-A*

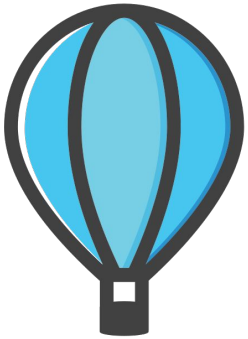
State Lattice

Overview

Background



Nav2 Smac Planners



In The Wild

Configuration

See Nav2 Docs For Full List

Create Potential Fields

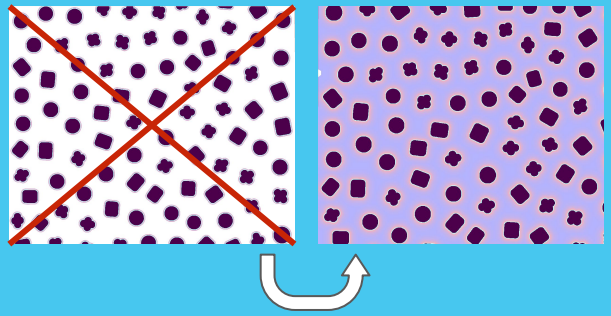
Cache Obstacle Heuristic

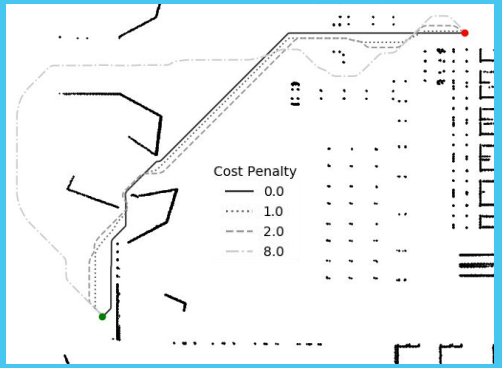
- For consecutive replanning in static spaces
- Less than 10 ms replans typical

Cost Penalty

- Cost: Penalizes higher cost areas*
- Reverse: Penalizes going in reverse
- Change: Penalizes not continuing last action
- Non-Straight: Penalizes non-straight actions
- Rotation: Penalizes pure rotations (Lattice only)

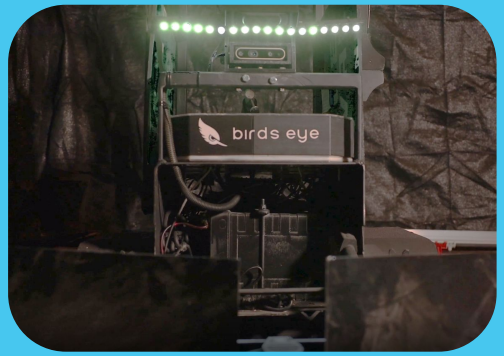
* Shared with cost-aware obstacle heuristic





Variable Cost Penalties - 2D-A*

In The Wild



Repository, Documentation, and Issue Tracker:

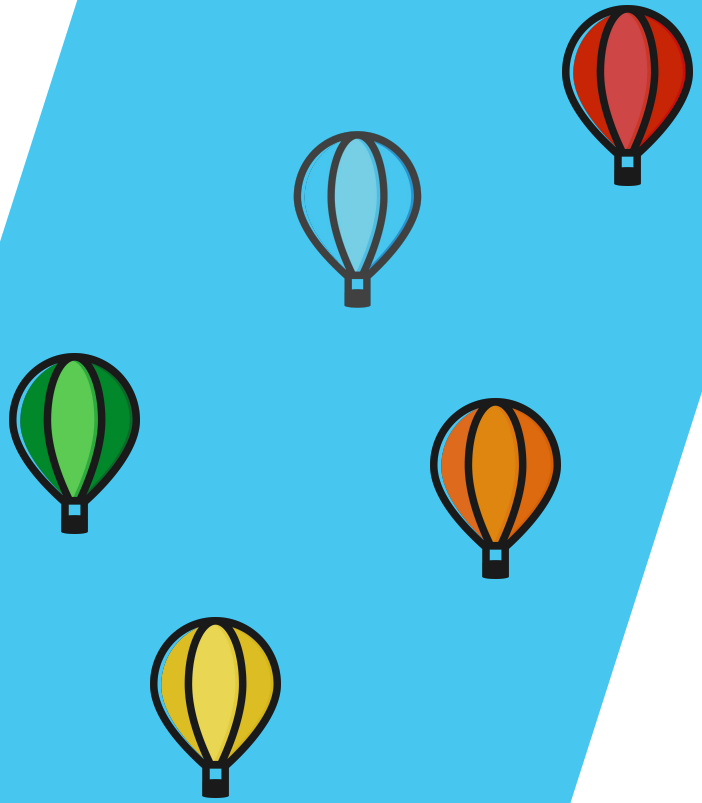
https://github.com/ros-planning/navigation2

https://discourse.ros.org/c/navigation

https://navigation.ros.org

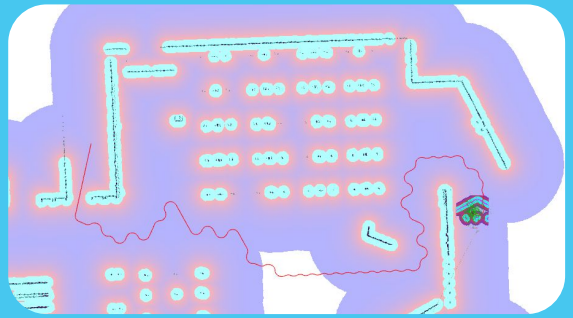
Interested in Getting Involved?
Join our Slack: https://bit.ly/3ssxidP

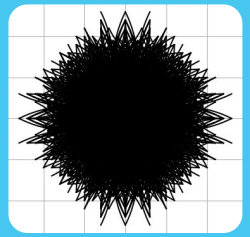
Steve Macenski
Senior Technical Lead - Samsung Research
s.macenski@samsung.com
stevenmacenski@gmail.com

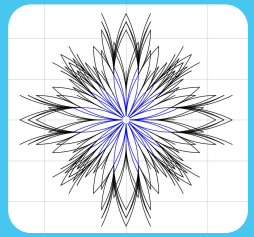


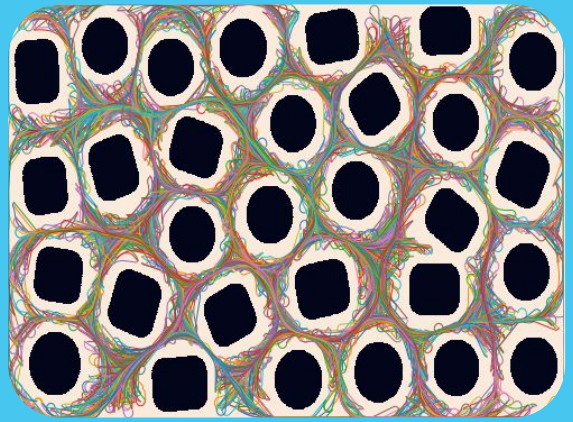
N A V 2

From the Desk









Configuration

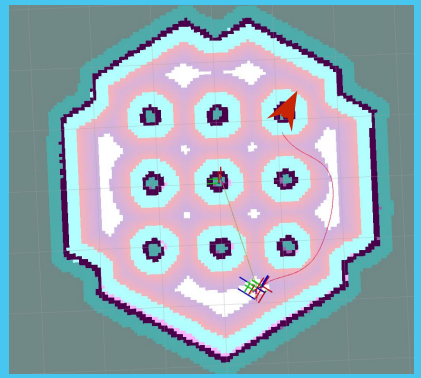
See Nav2 Docs For Full List

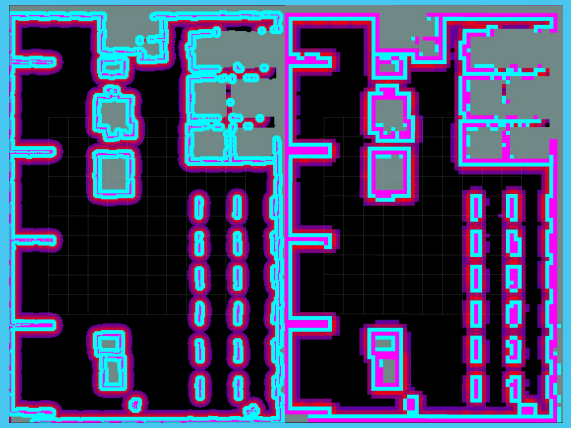
Termination Conditions
- Max Planning Time / Iterations
- Planning Tolerance / Iterations on Approach

Downsample Costmaps

Analytic Expansion
- Ratio
- Maximum Length

Angular Quantizations





Smac Planner - Features

Dynamic Graph Creation

- Constructs graph on expansion
- No run-time lookups
- **NEW** ~25% speed-up with Robin Hood Hashing

Smoothing Options

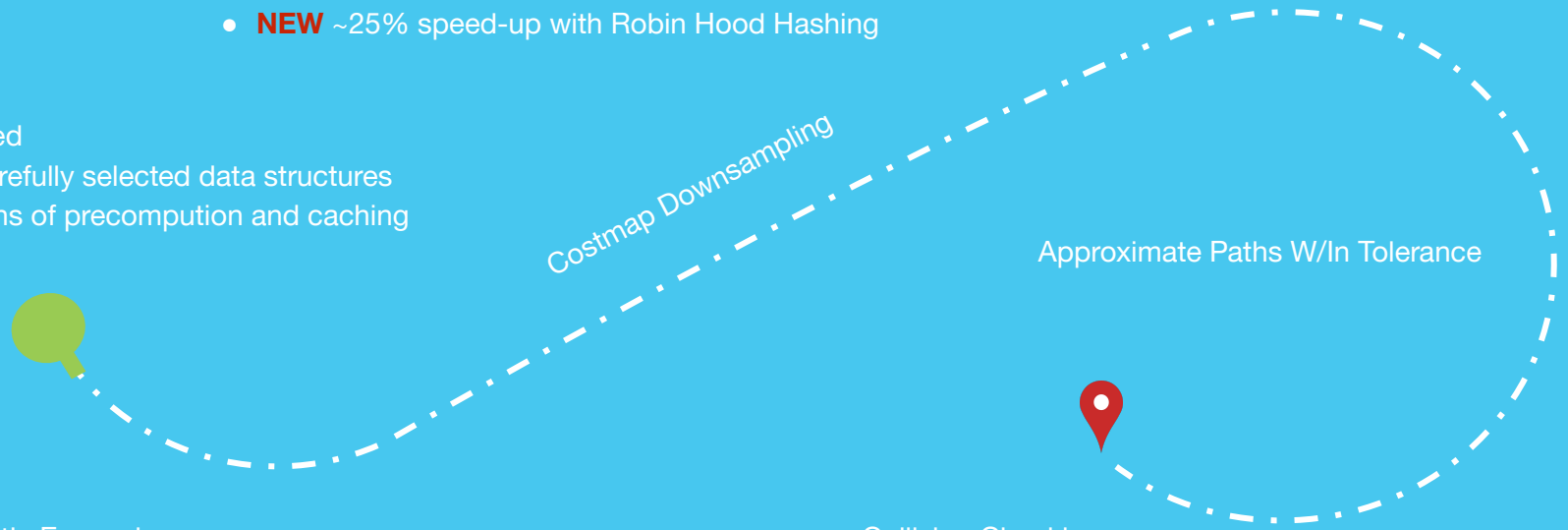
- Basic gradient descent
- Collision & curvature constrained

Optimized

- Carefully selected data structures
- Tons of precompution and caching

Costmap Downsampling

Approximate Paths W/In Tolerance



Analytic Expansions

- Uses motion model to find exact path to goal
- Computed more frequently closer to the goal
- Significantly speeds up on approach to goal

Collision Checking

- Checks if center cost is less than min possibly inscribed
  - If not, checks full SE2 footprint
  - If circular, checks center inflated costs