oxnet science

Modelling Mobile Robot Navigation from Data

Professor Nick Hawes
Oxford Robotics Institute | Pembroke College | The Alan Turing Institute
http://nickhaw.es nickh@robots.ox.ac.uk @hawesie

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LONG-LIVED SYSTEMS
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We research algorithms for **mission planning** for autonomous systems

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Example **Mission:** Greet a visitor at a given time

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Transport Systems Catapult, Milton Keynes, UK

120 days of *autonomous* behaviour

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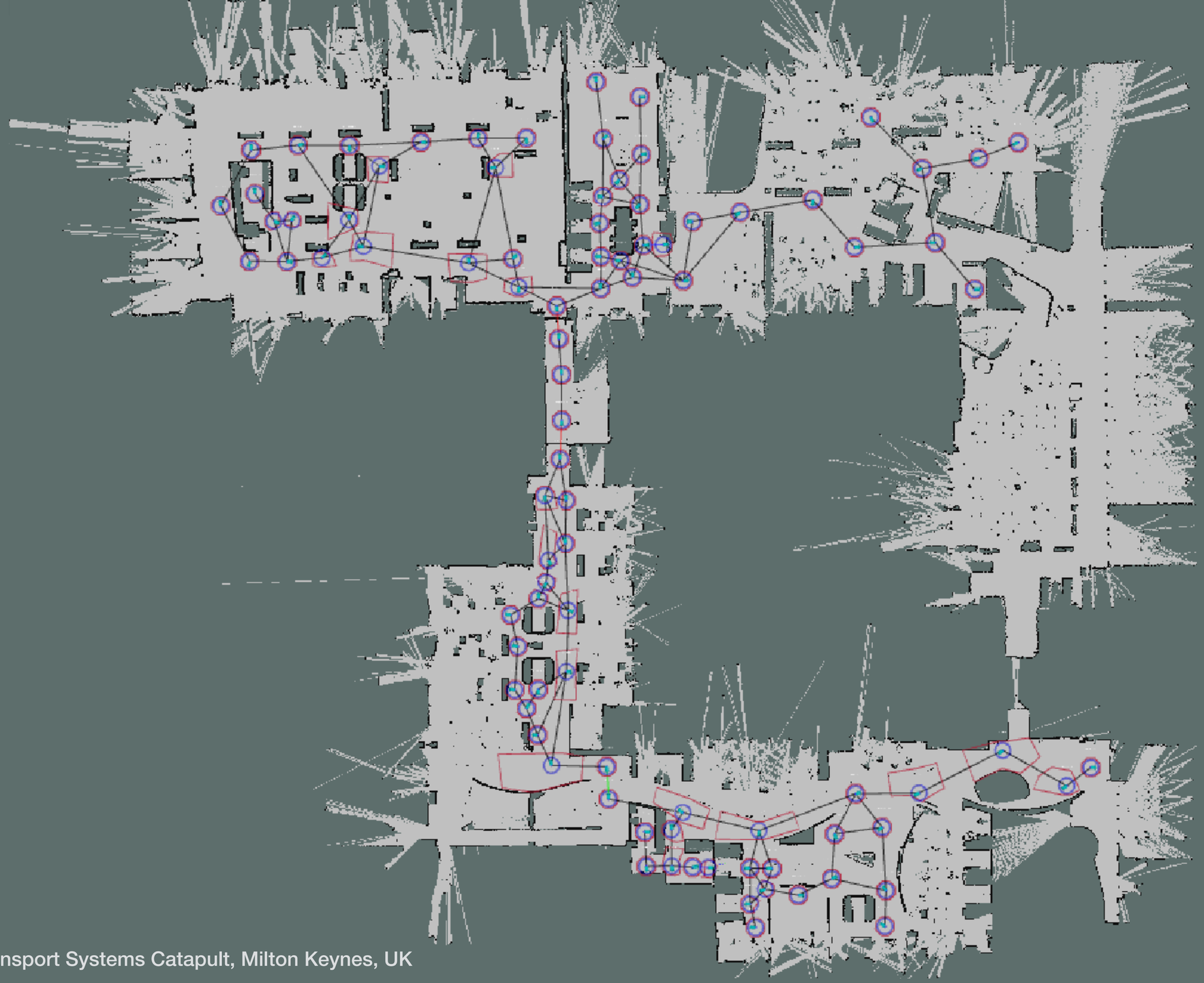

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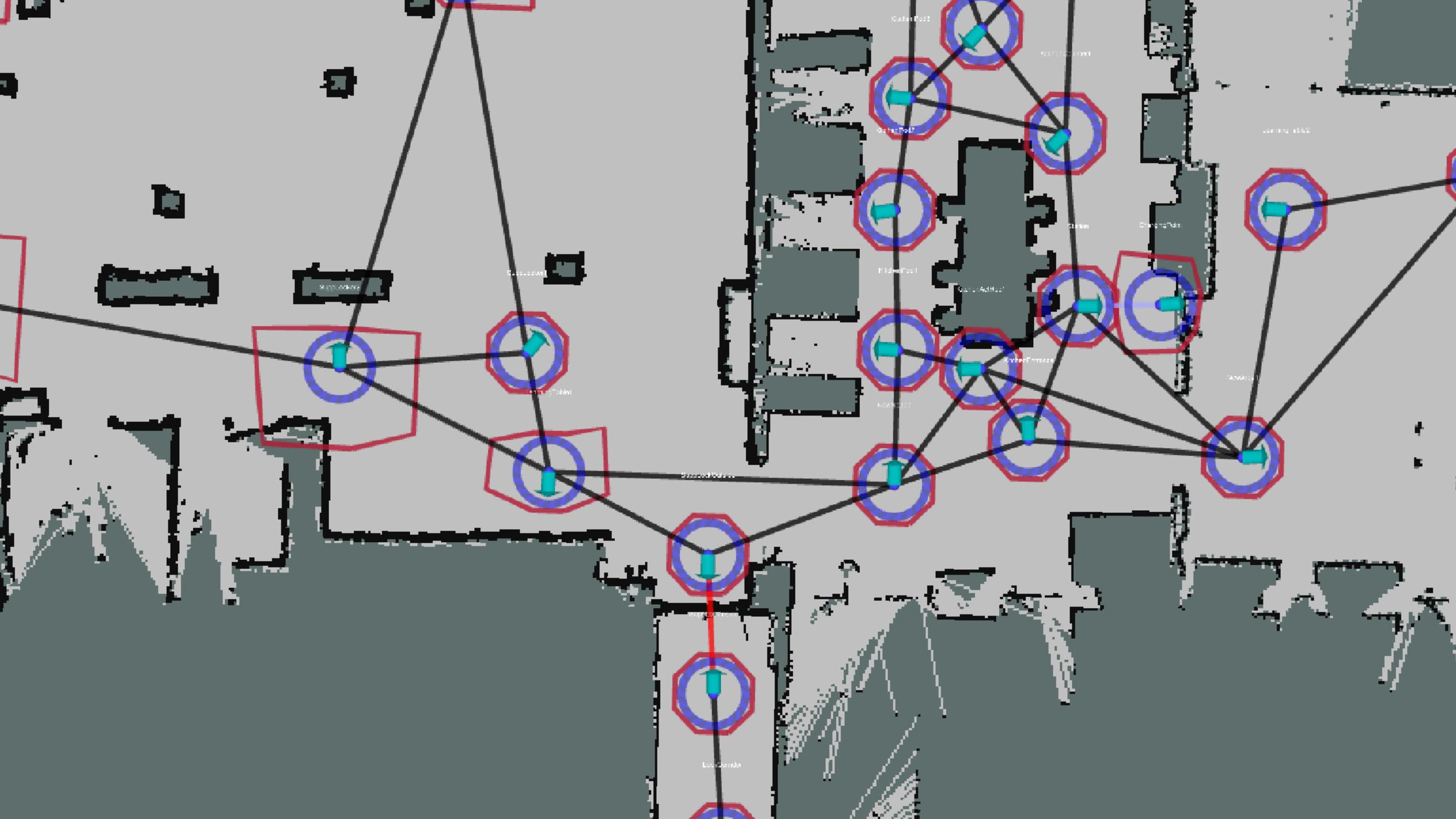
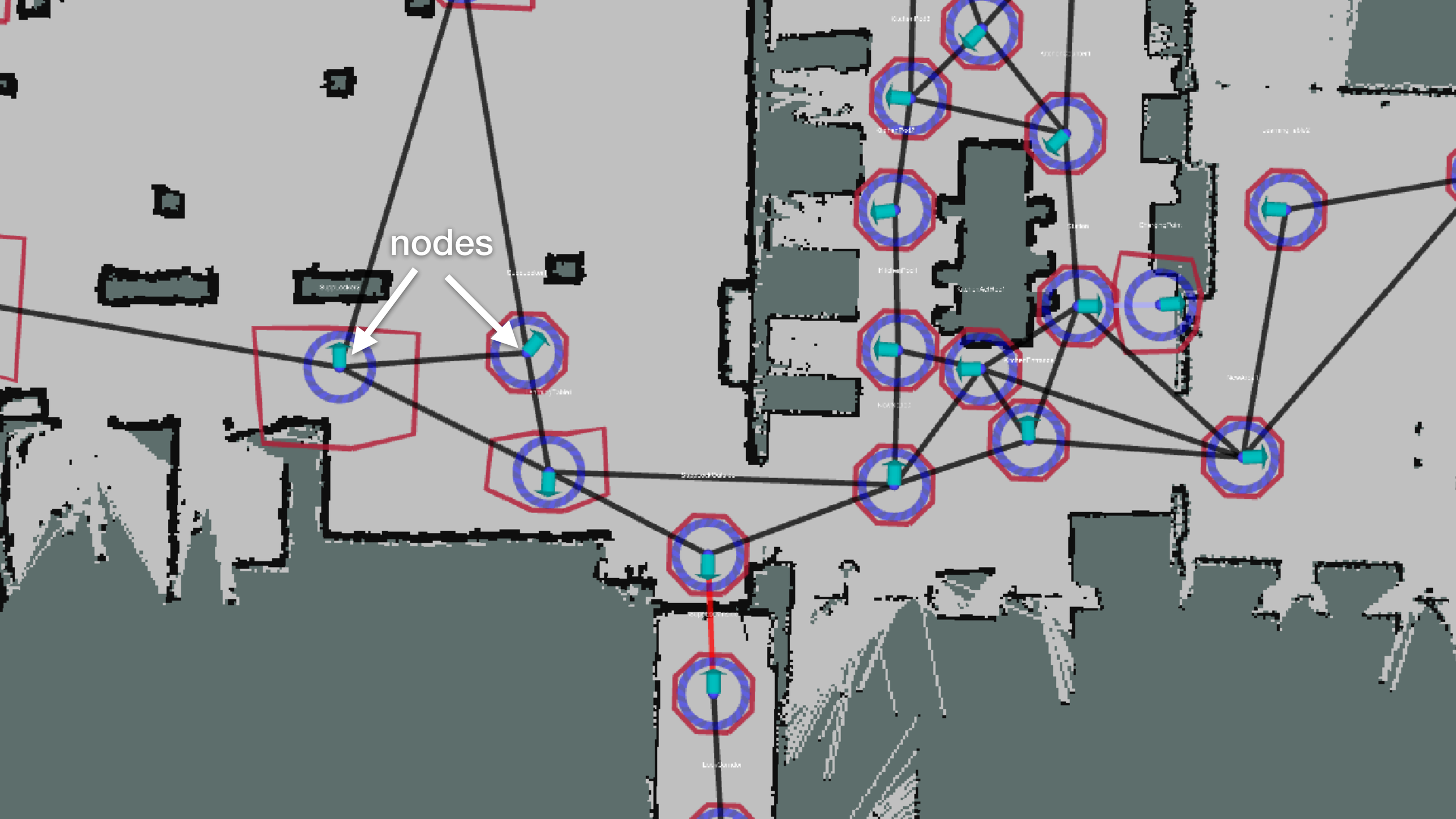
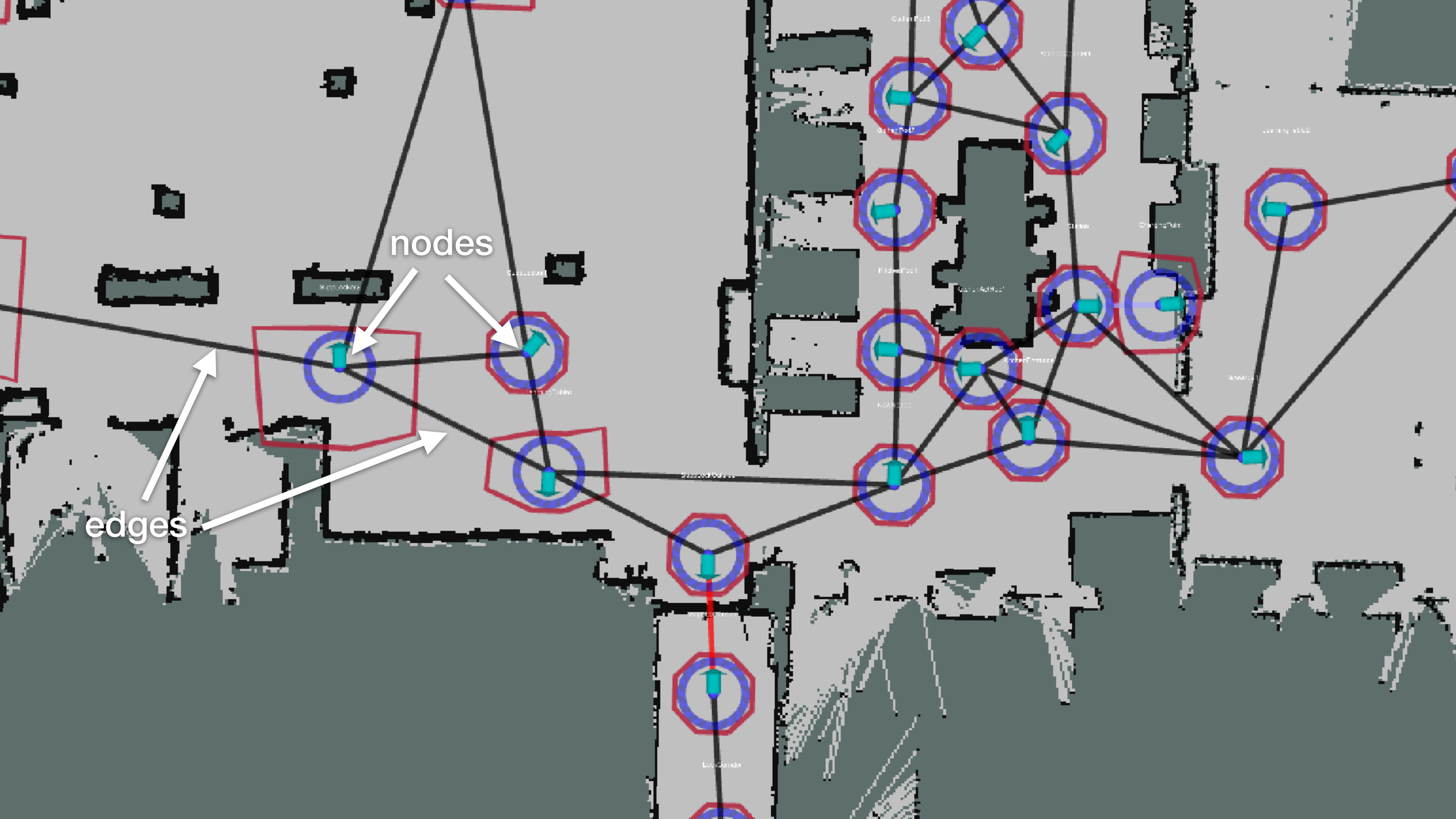
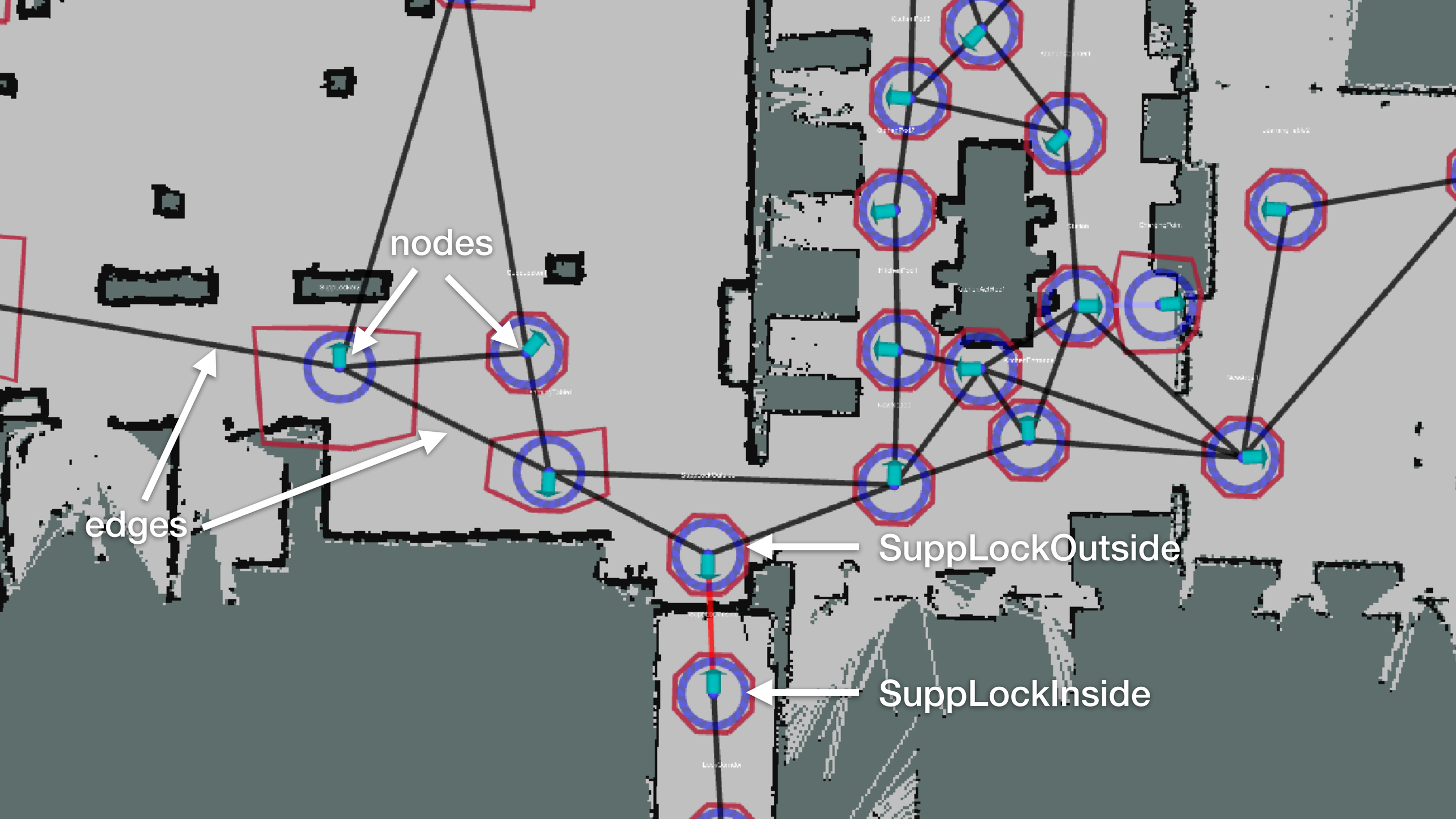
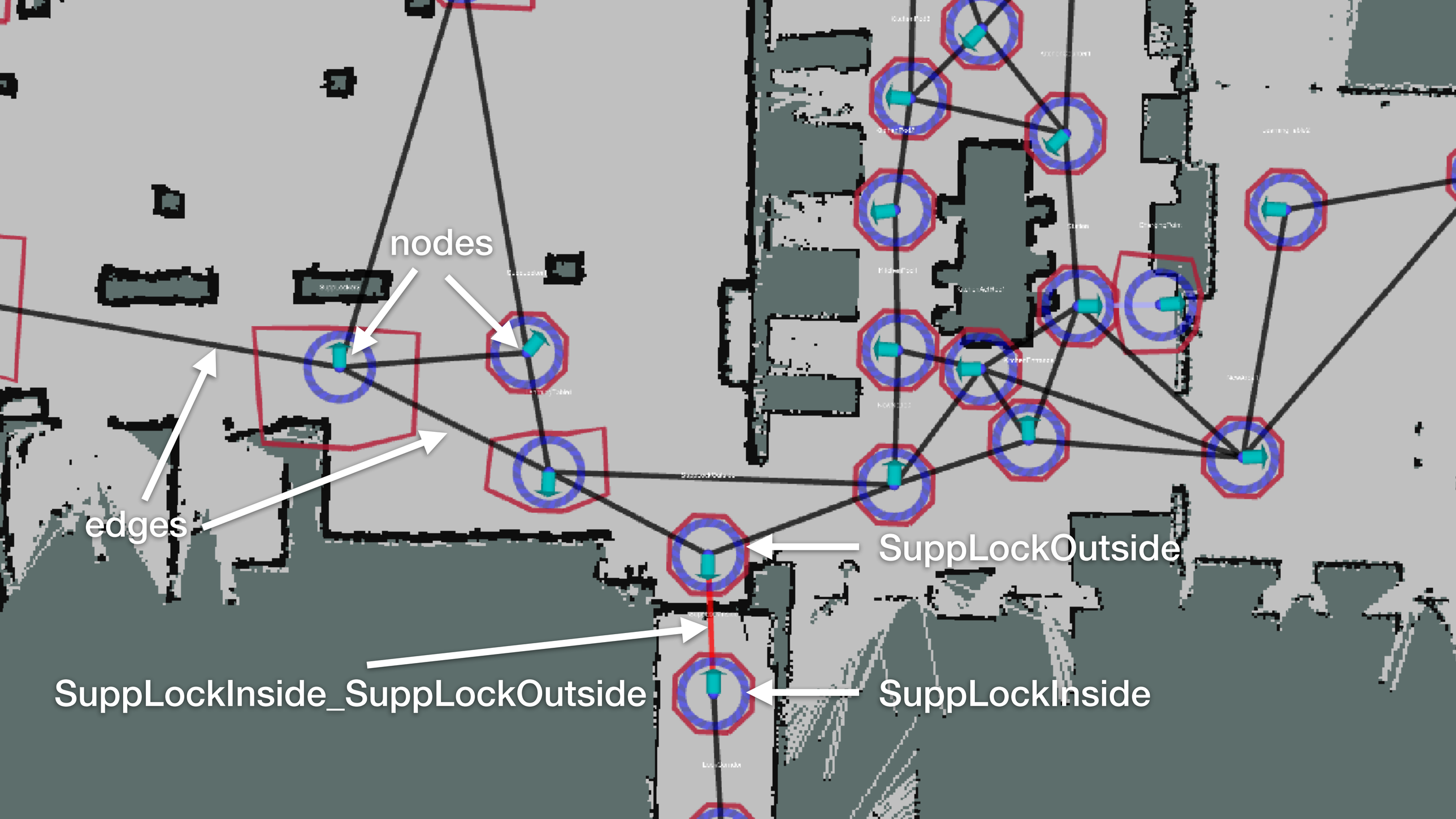
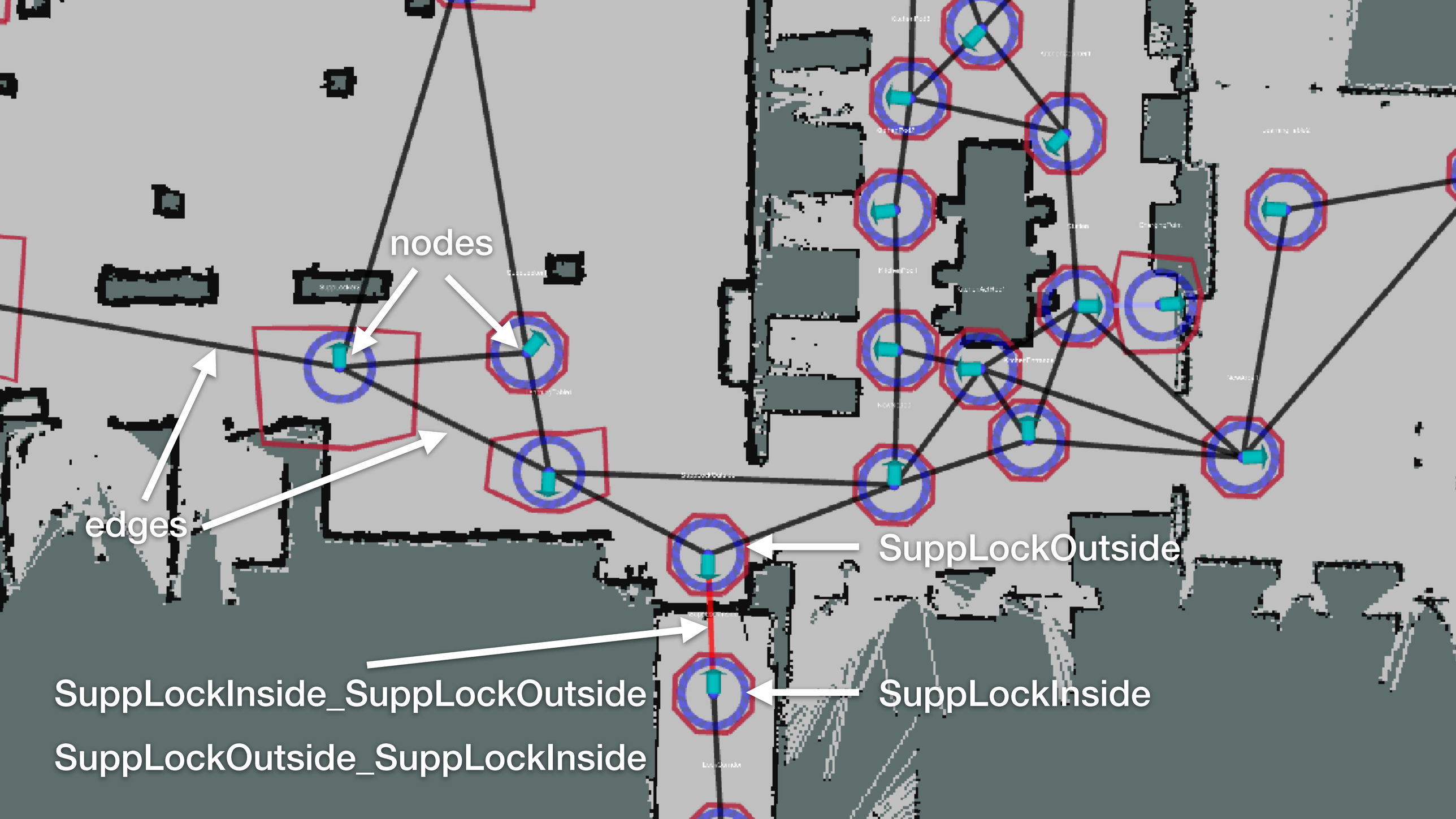


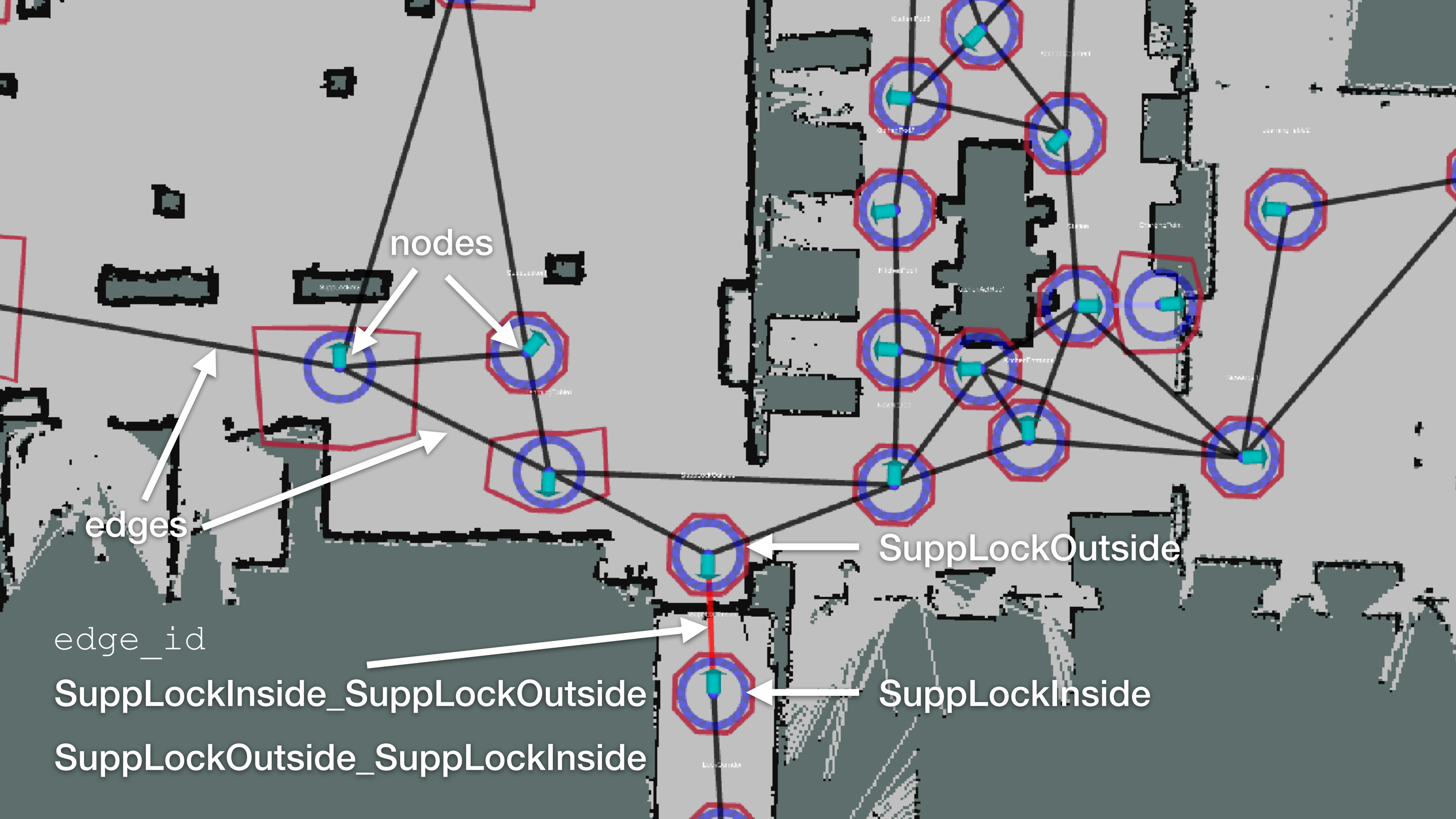

nodes

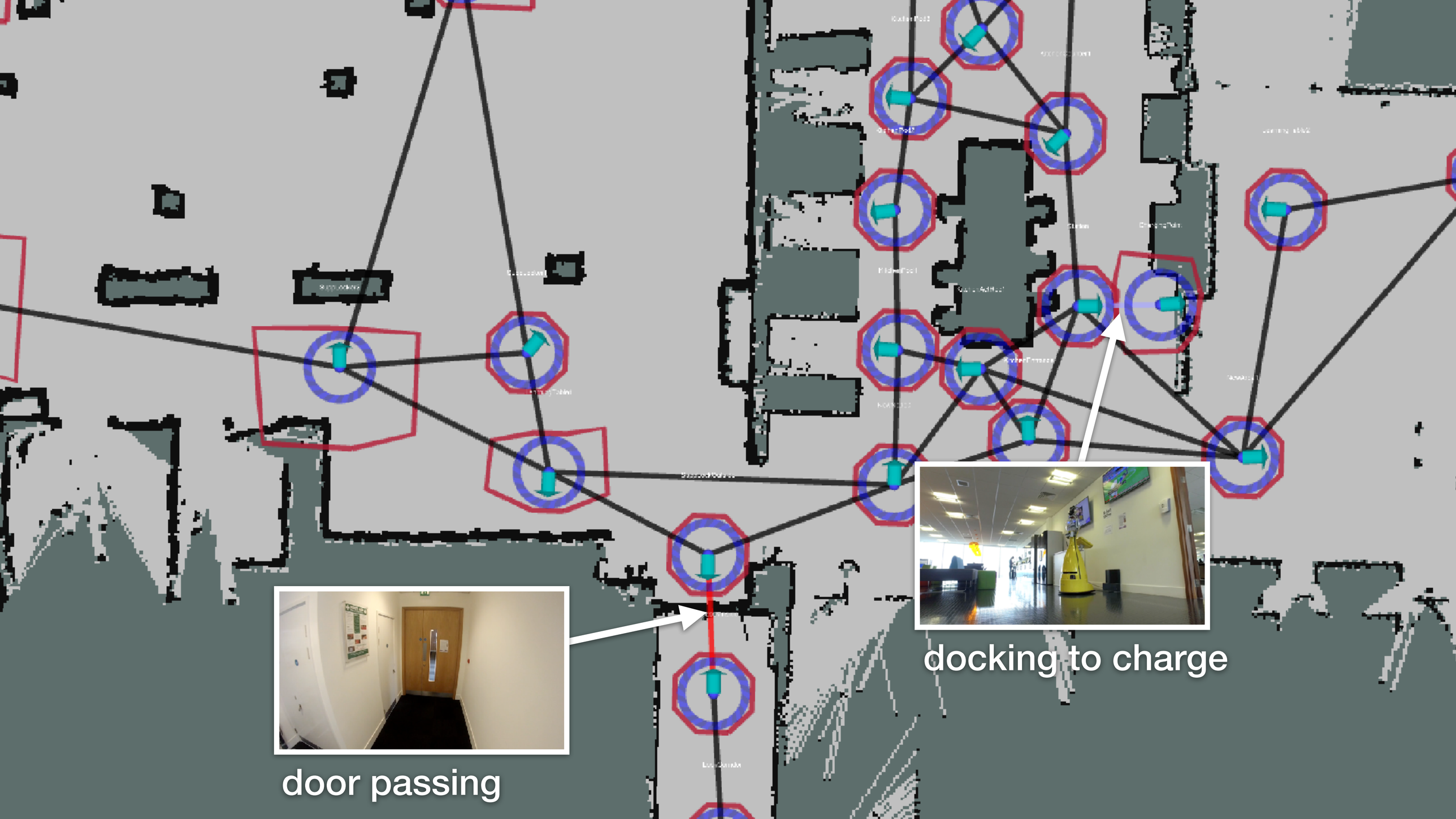

nodes
edges

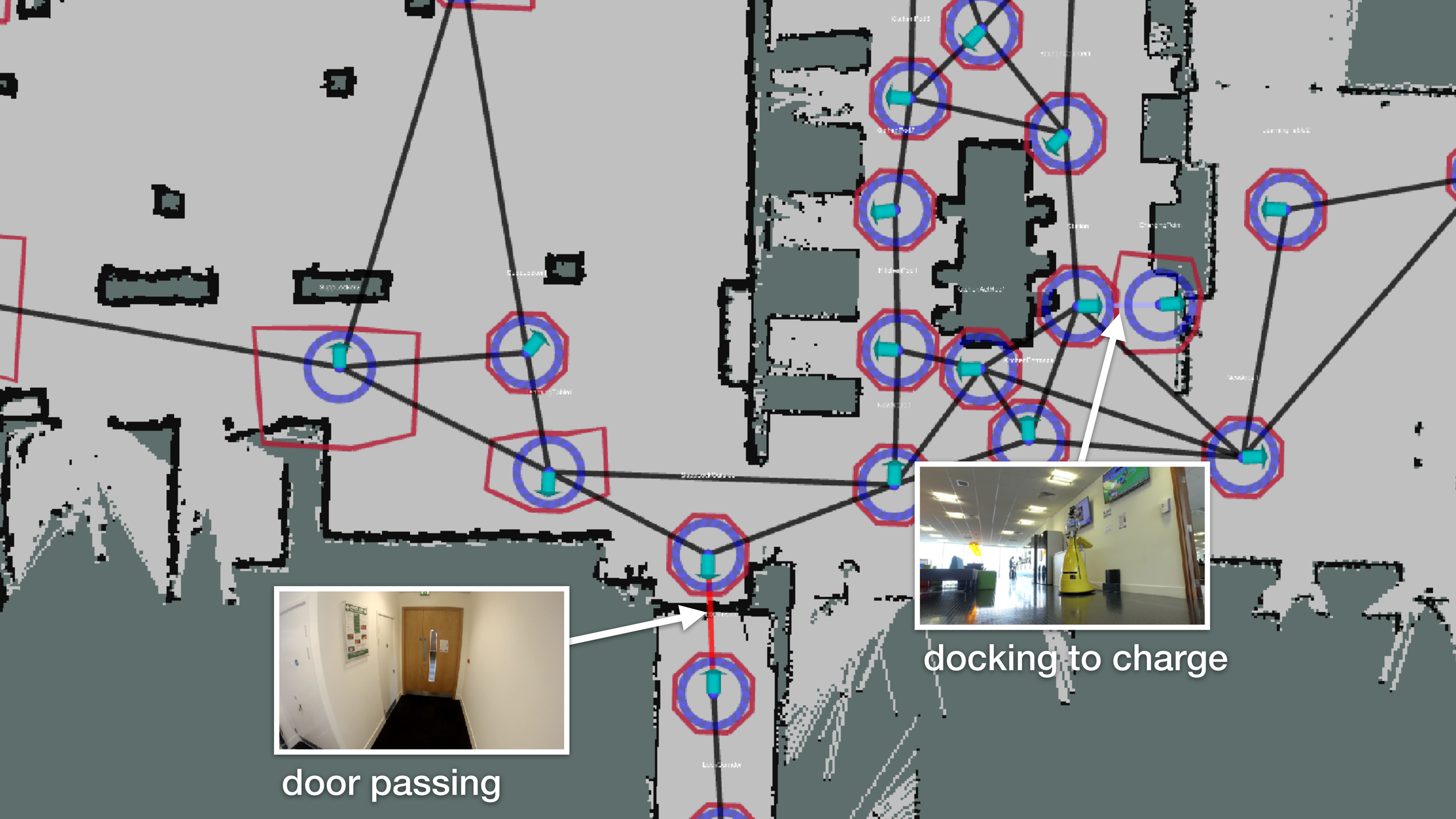

nodes
edges
SuppLockOutside
SuppLockInside


nodes
edges
SuppLockOutside
SuppLockInside_SuppLockOutside
SuppLockInside


nodes
edges
SuppLockOutside
SuppLockInside_SuppLockOutside
SuppLockInside
SuppLockOutside_SuppLockInside


nodes
edges
SuppLockOutside
edge_id
SuppLockInside_SuppLockOutside
SuppLockOutside_SuppLockInside
SuppLockInside


docking to charge
door passing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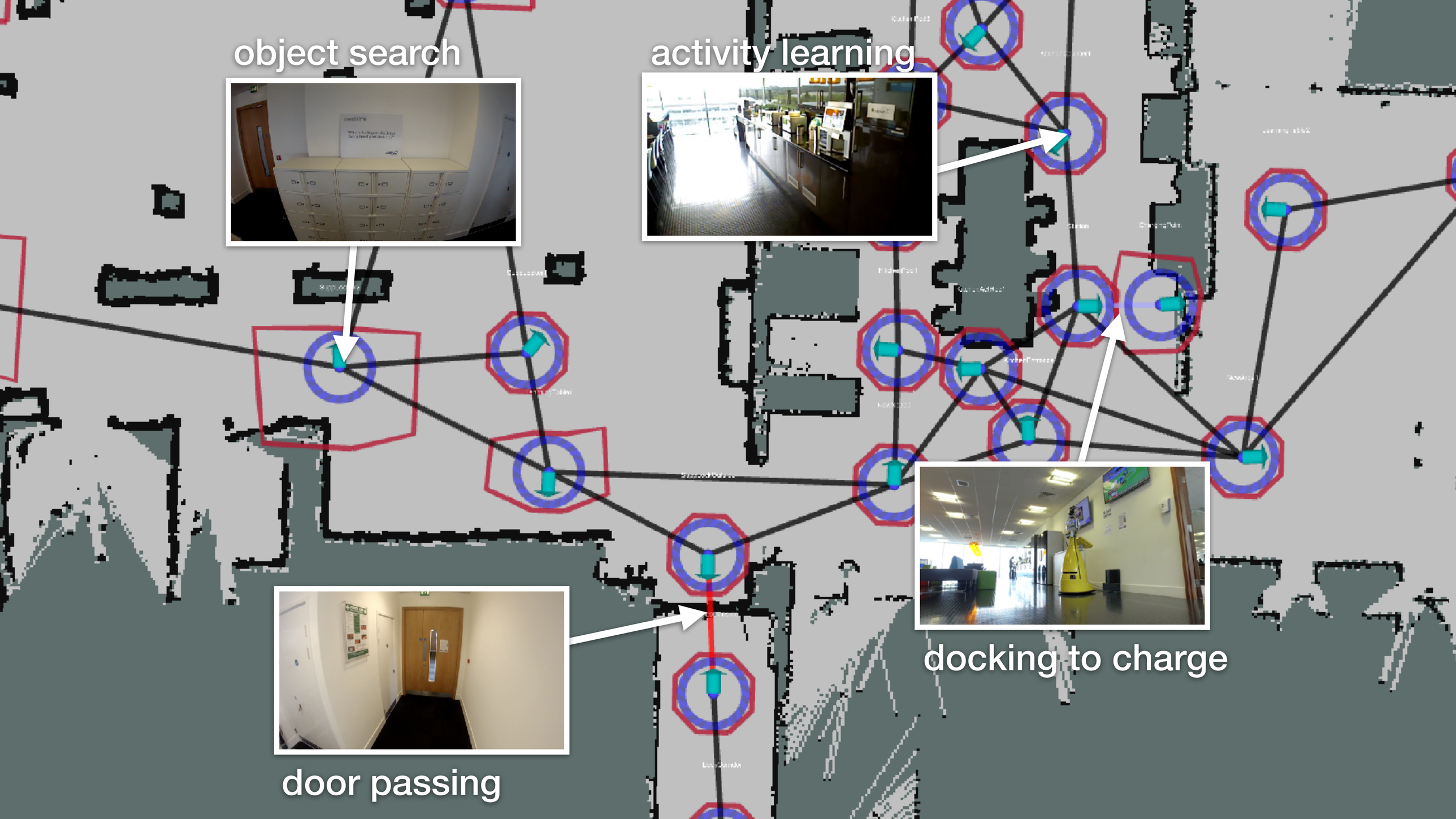
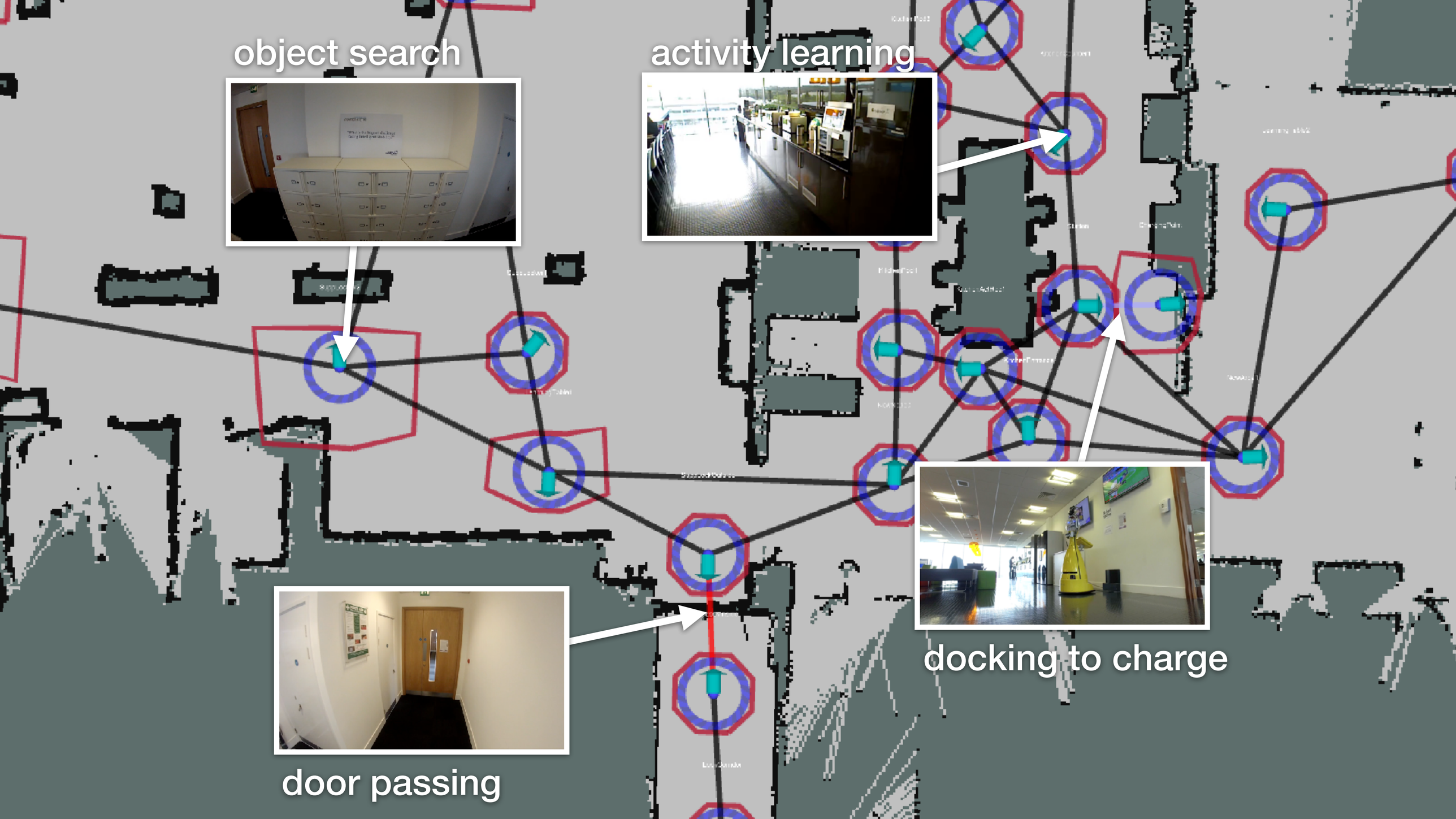

object search
activity learning
docking to charge
door passing


object search
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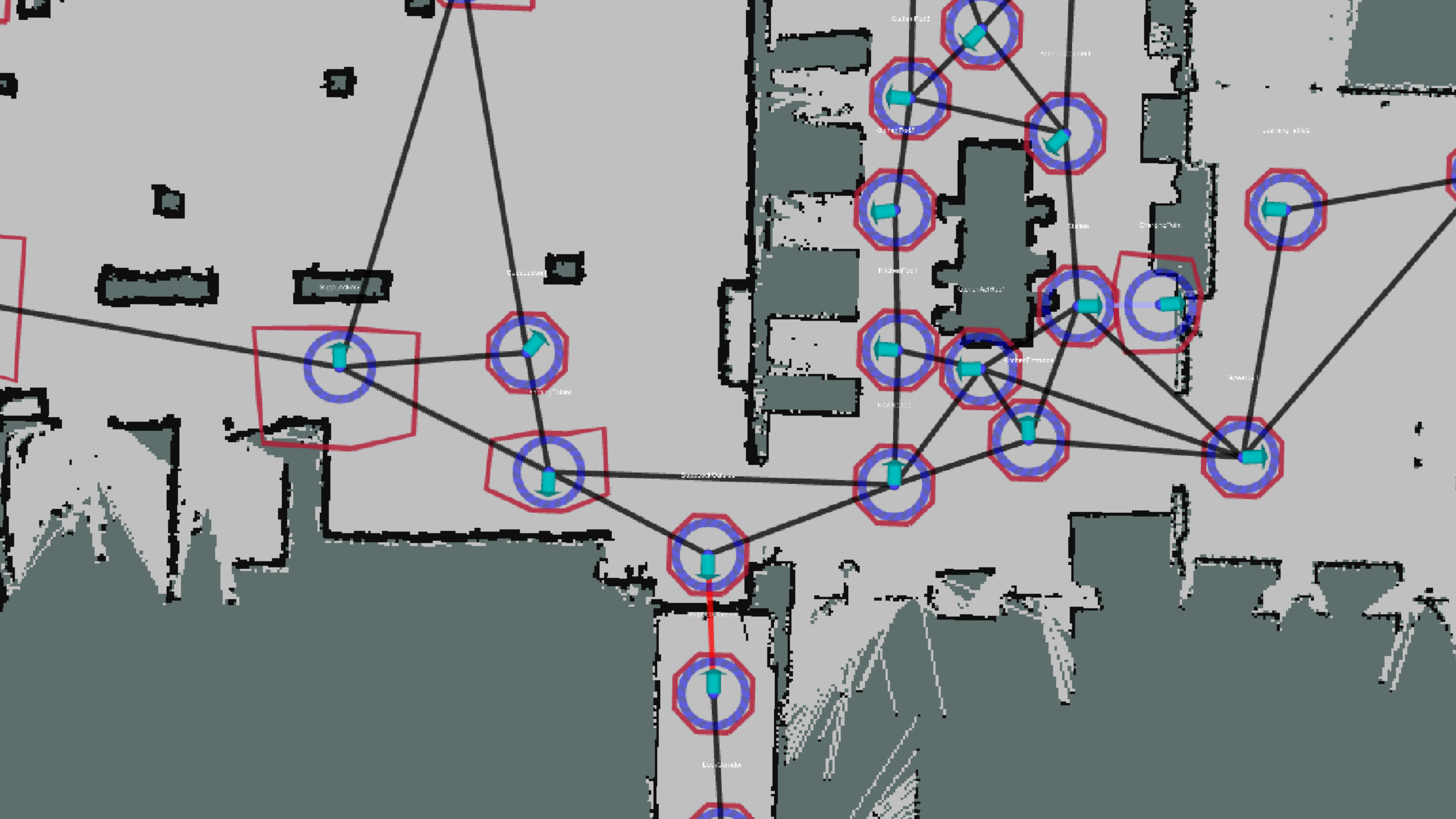

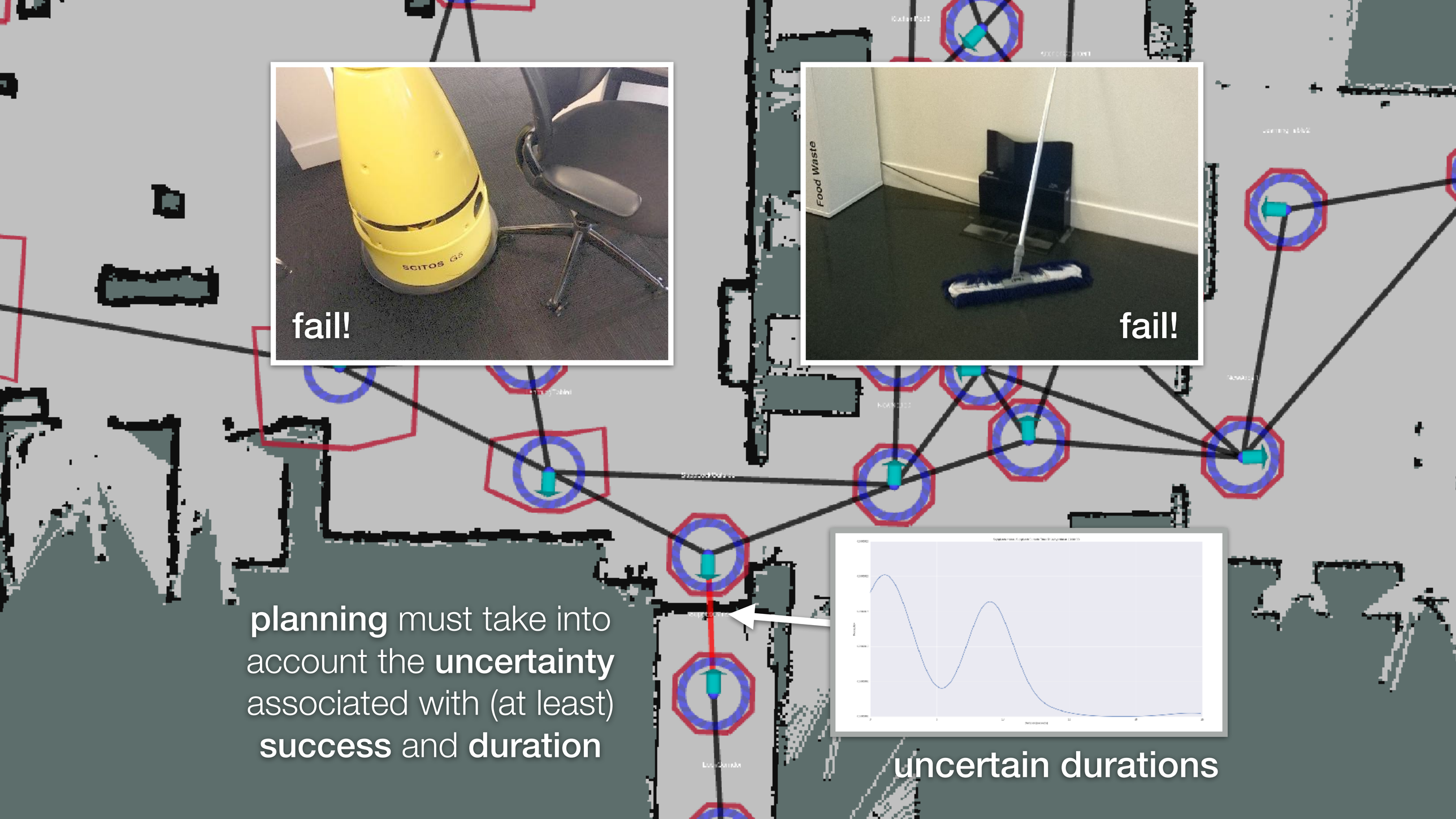
fail!
SCITOS G5
fail!
Food Waste
planning must take into account the uncertainty associated with (at least) success and duration
uncertain durations

Markov Decision Process (MDP)

$$\mathcal{M} = \langle S, A, T, C \rangle$$

states

actions

transition probs

action costs

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states

actions

transition probs

action costs

defined by the map and task

Markov Decision Process (MDP)

$$\mathcal{M} = \langle S, A, T, C \rangle$$

states

actions

transition probs

action costs

defined by the map and task

learnt through experience

Markov Decision Process (MDP)

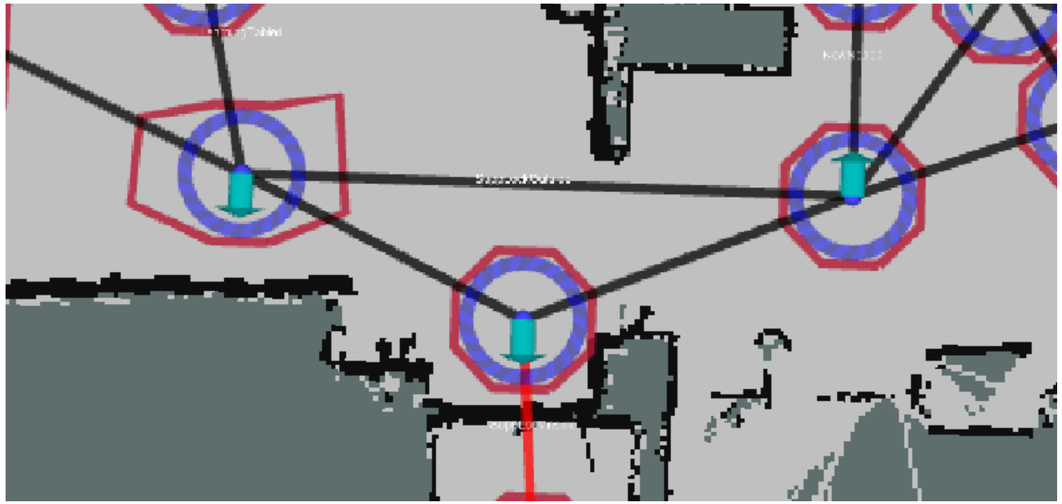
$$\mathcal{M} = \langle S, A, T, C \rangle$$

states

actions

transition probs

action costs



Markov Decision Process (MDP)

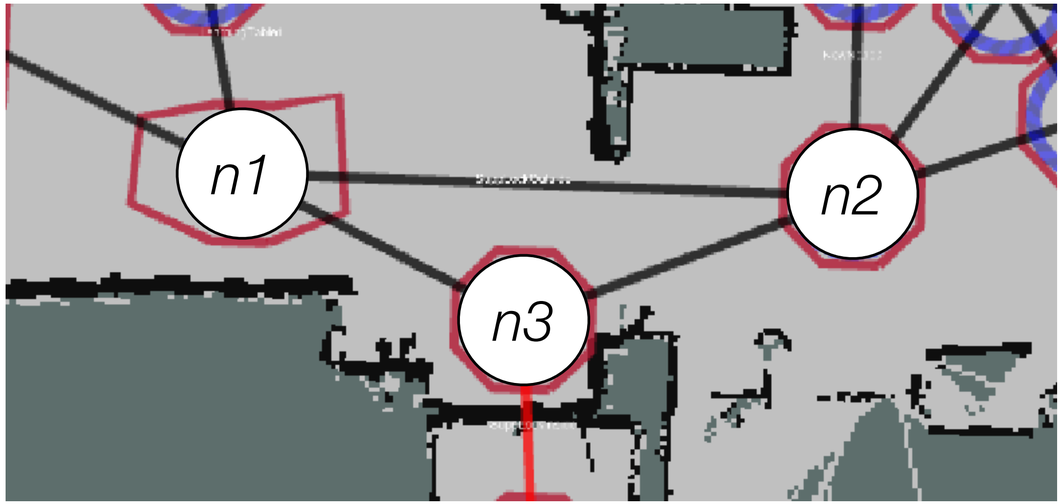
$$\mathcal{M} = \langle S, A, T, C \rangle$$

states

actions

transition probs

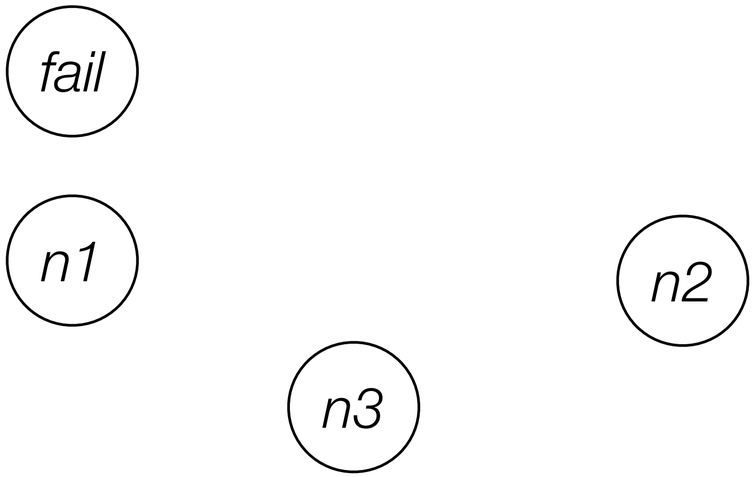
action costs



Markov Decision Process (MDP)

$$\mathcal{M} = \langle S, A, T, C \rangle$$

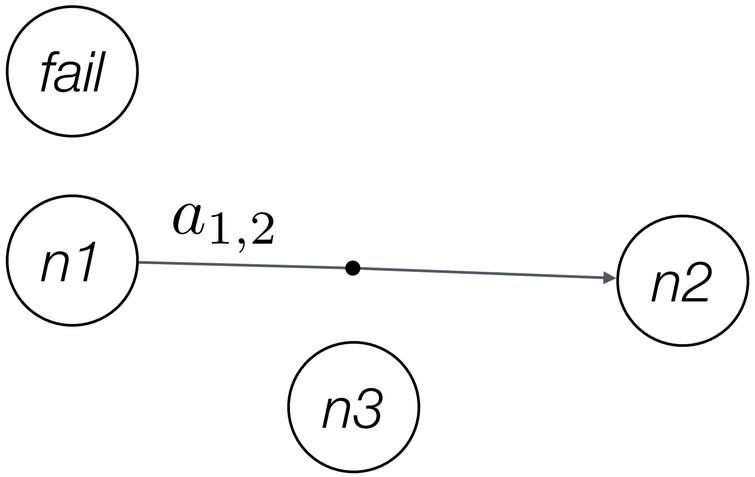
$n1, n2, n3, fail \in S$



Markov Decision Process (MDP)

$$\mathcal{M} = \langle S, A, T, C \rangle$$

$n1, n2, n3, fail \in S$ $\qquad$ $a_{1,2} \in A$



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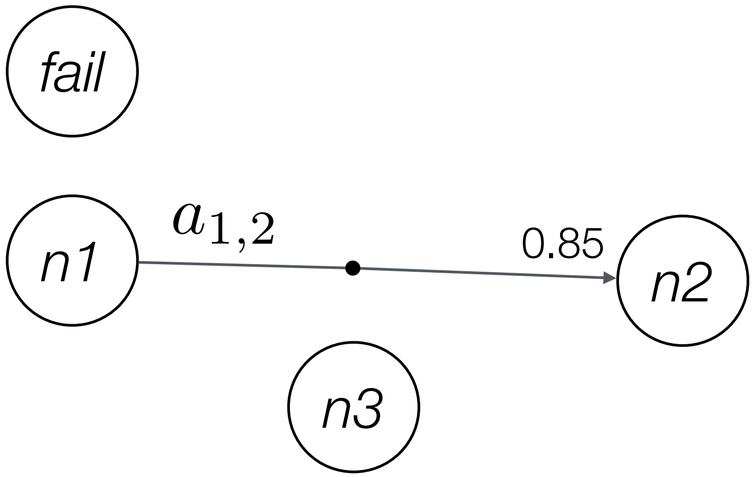

$$T(n1, a_{1,2}, n2) = 0.85$$

Markov Decision Process (MDP)

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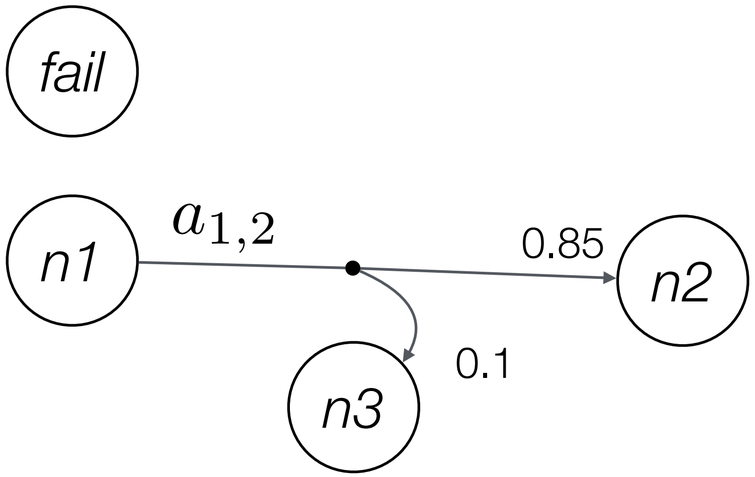

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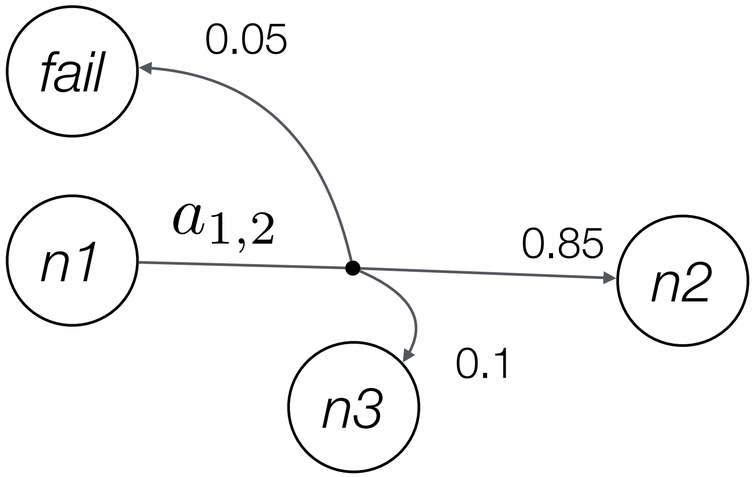

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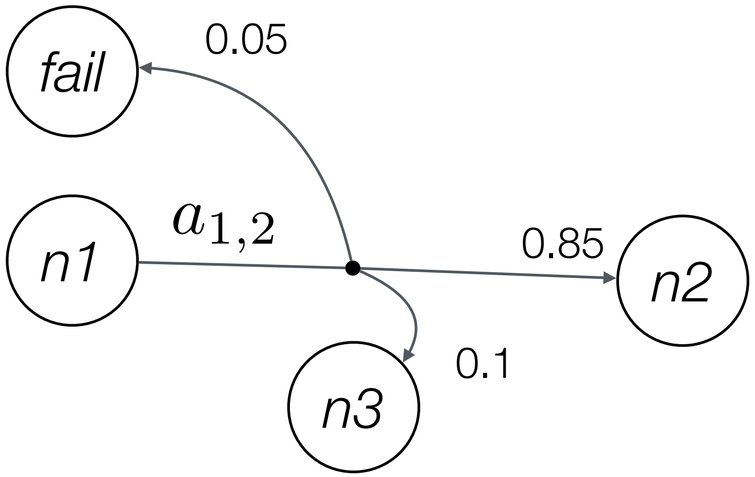
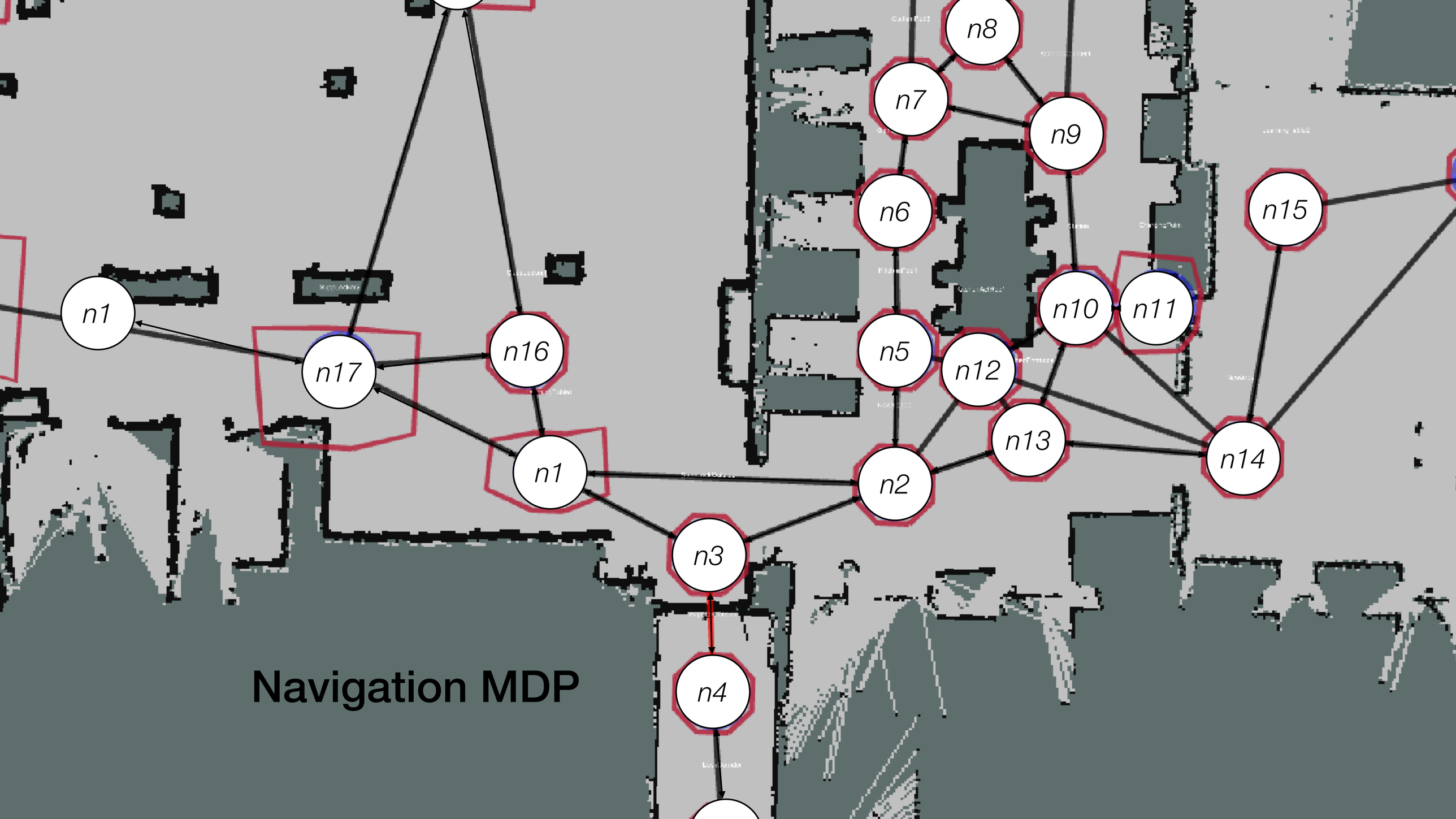


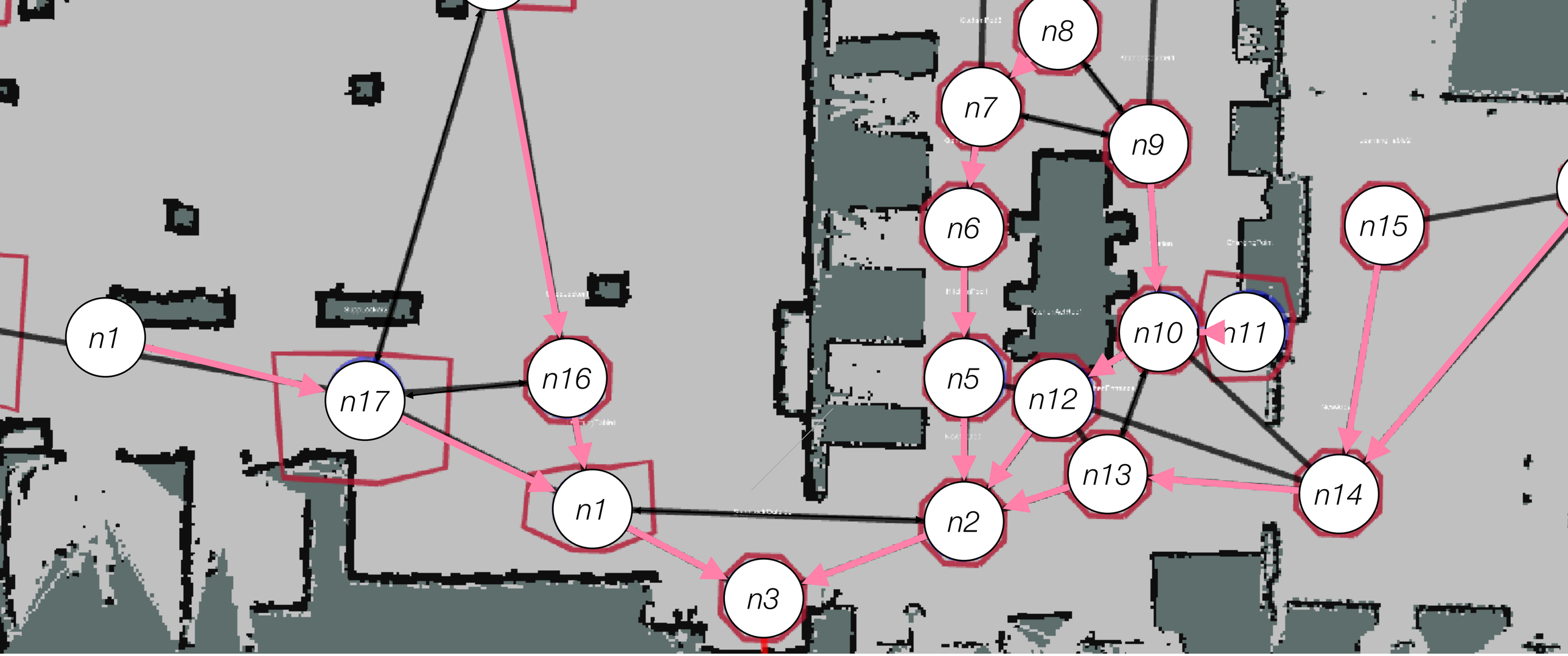
(seconds)

$T(n1, a_{1,2}, n2) = 0.85$
$T(n1, a_{1,2}, n3) = 0.1$
$T(n1, a_{1,2}, fail) = 0.05$

$C(n1, a_{1,2}, n2) = 5$
$C(n1, a_{1,2}, n3) = 3$
$C(n1, a_{1,2}, fail) = 12$



Navigation MDP



An MDP is **solved** to produce a **policy**. A **policy** tells the robot the **best action** (*edge*) to take in each **state** (*node*) in order to reach a **goal state**.

(probability)

$$T(n1, a_{1,2}, n2) = 0.85$$
$$T(n1, a_{1,2}, n3) = 0.1$$
$$T(n1, a_{1,2}, fail) = 0.05$$

(seconds)

$$C(n1, a_{1,2}, n2) = 5$$
$$C(n1, a_{1,2}, n3) = 3$$
$$C(n1, a_{1,2}, fail) = 12$$

Where do these numbers come from?

(probability)

$$T(n1, a_{1,2}, n2) = 0.85$$
$$T(n1, a_{1,2}, n3) = 0.1$$
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(seconds)

$$C(n1, a_{1,2}, n2) = 5$$
$$C(n1, a_{1,2}, n3) = 3$$
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Where do these numbers come from?

Every time the robot moves across an edge it records the following facts

(probability)

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$$T(n1, a_{1,2}, n3) = 0.1$$
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(seconds)

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Where do these numbers come from?

Every time the robot moves across an edge it records the following facts

start node target node edge final node

(probability)

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Where do these numbers come from?

Every time the robot moves across an edge it records the following facts

start node target node edge final node

time reach to influence zone time to move to waypoint

(probability)

$$T(n1, a_{1,2}, n2) = 0.85$$
$$T(n1, a_{1,2}, n3) = 0.1$$
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(seconds)

$$C(n1, a_{1,2}, n2) = 5$$
$$C(n1, a_{1,2}, n3) = 3$$
$$C(n1, a_{1,2}, fail) = 12$$

Where do these numbers come from?

Every time the robot moves across an edge it records the following facts

start node target node edge final node

time reach to influence zone time to move to waypoint

did it succeed?

Activities rviz Thu 23:31 en

multi_rob_gazebo.rviz* - RViz

File Panels Help

Interact | Move Camera | Select | Focus Camera | Measure | 2D Pose Estimate | 2D Nav Goal | Publish Point

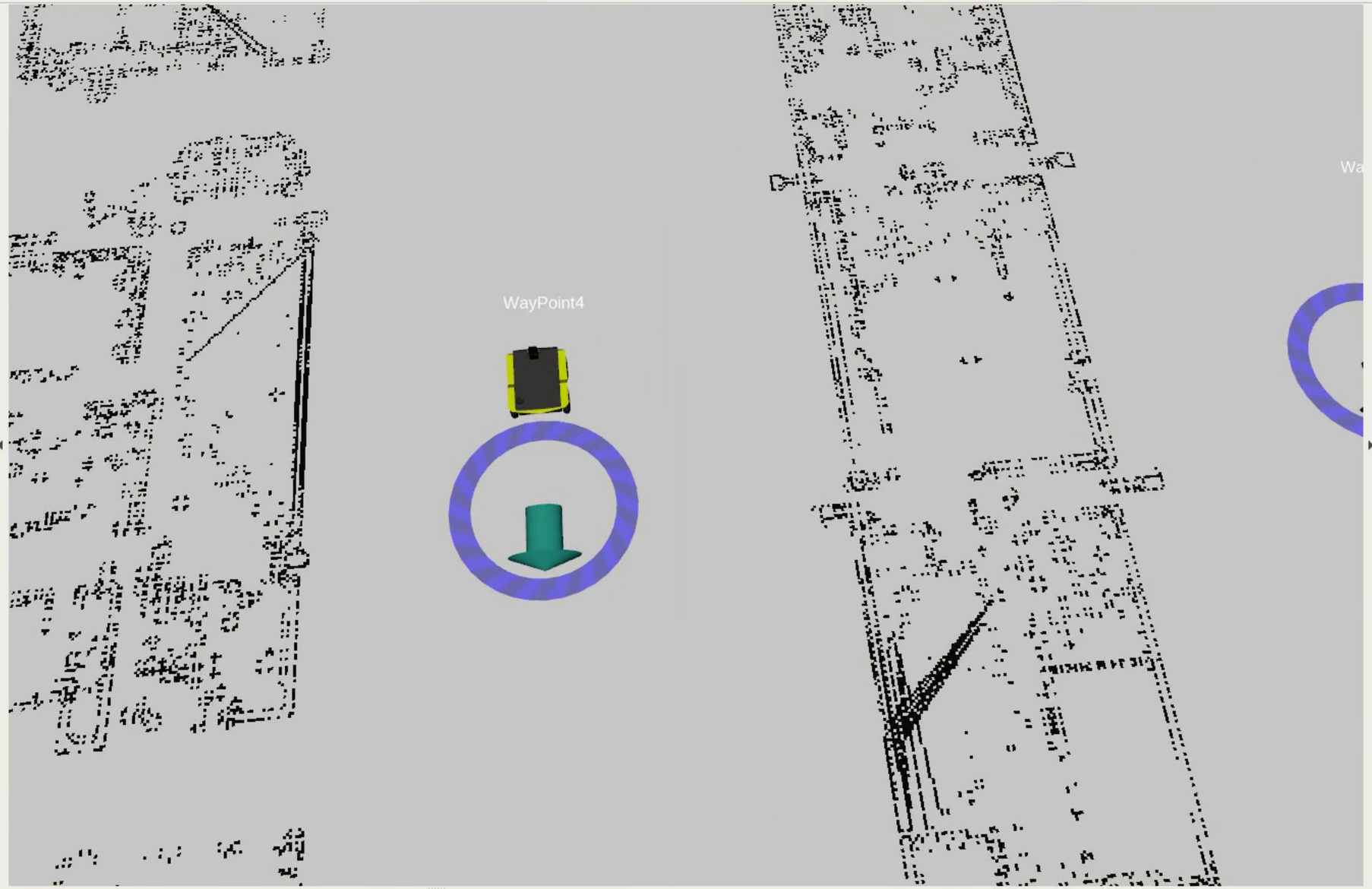
Displays

- Global Status: Ok
  - Fixed Frame: OK
- Map
- Topological Map
  - Visualisation
  - Waypoint Markers
  - Edge Markers
- Robot 0 (blue)
  - PoseArray
  - LaserScan
  - Global path
  - Local path
  - Local costmap
  - Global costmap
    - Status: Warn
    - Topic: /robot_0/move_base_flex/...
    - Alpha: 0.2
    - Color Scheme: costmap
    - Draw Behind
    - Resolution: 0.019
    - Width: 1277
    - Height: 937
    - Position: 0; 0; 0
    - Orientation: 0; 0; 0; 1
    - Unreliable
    - Use Timestamp
  - Footprint
  - PoseWithCovariance
  - RobotModel
  - Eband Viz
- Robot 1 (red)
- Robot 2 (cyan)
- Robot 3 (magenta)
- Robot 4 (yellow)
- Intersection Markers
- PointCloud2

Add | Duplicate | Remove | Rename

Tool Properties

- Interact
- 2D Pose Estimate
  - Topic: /robot_0/initialpose
  - X std deviation: 0.5
  - Y std deviation: 0.5



Time

ROS Time: 12.70 | ROS Elapsed: 12.70 | Wall Time: 1596148275.23 | Wall Elapsed: 17.34 | Experimental

Reset **Left-Click:** Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift:** More options. 31 fps

Activities rviz Thu 23:31 en

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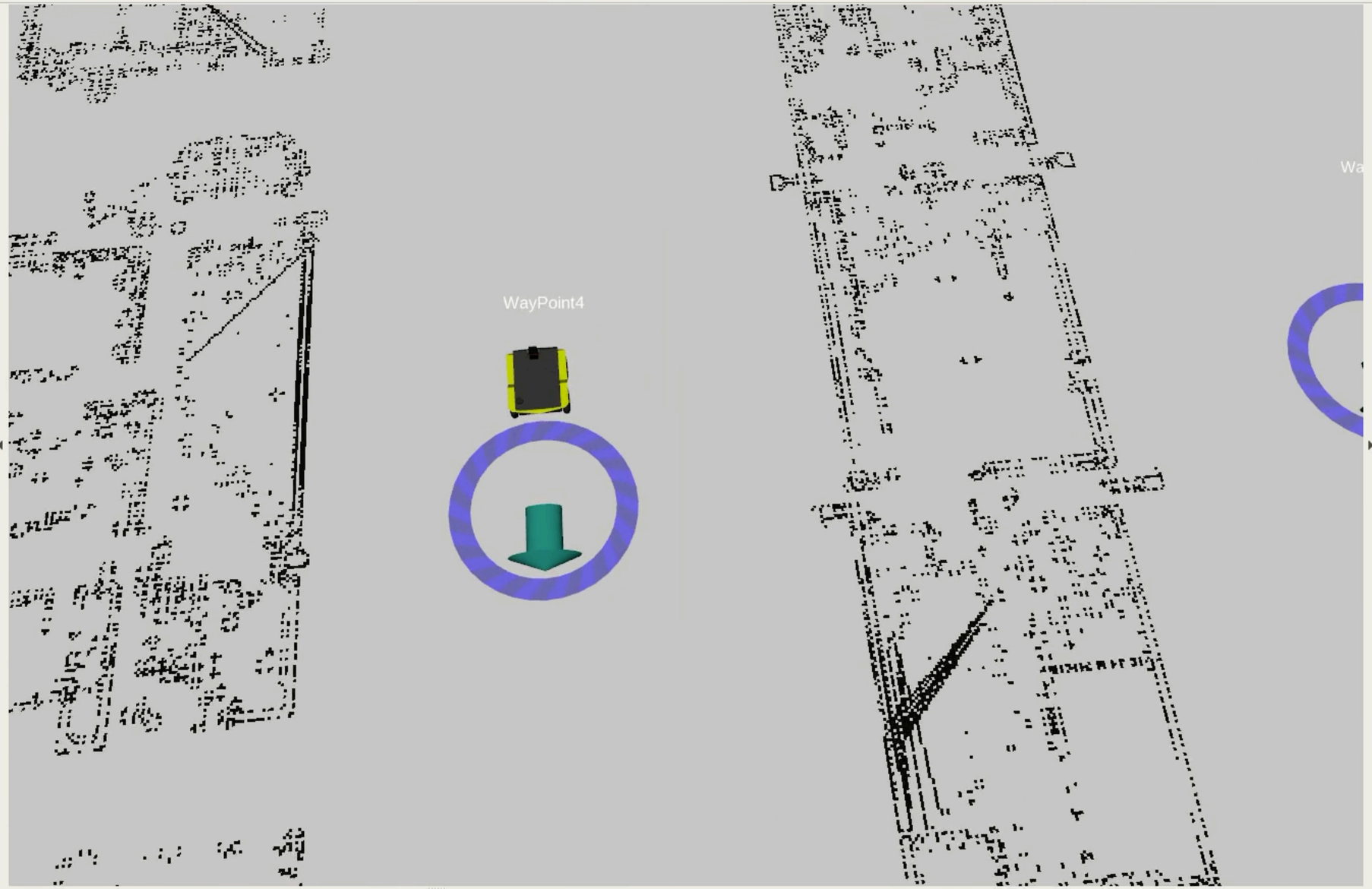
- 2D Pose Estimate
  - Topic: /robot_0/initialpose
  - X std deviation: 0.5
  - Y std deviation: 0.5



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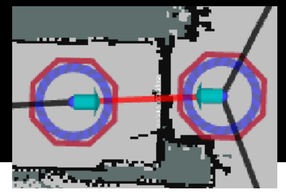
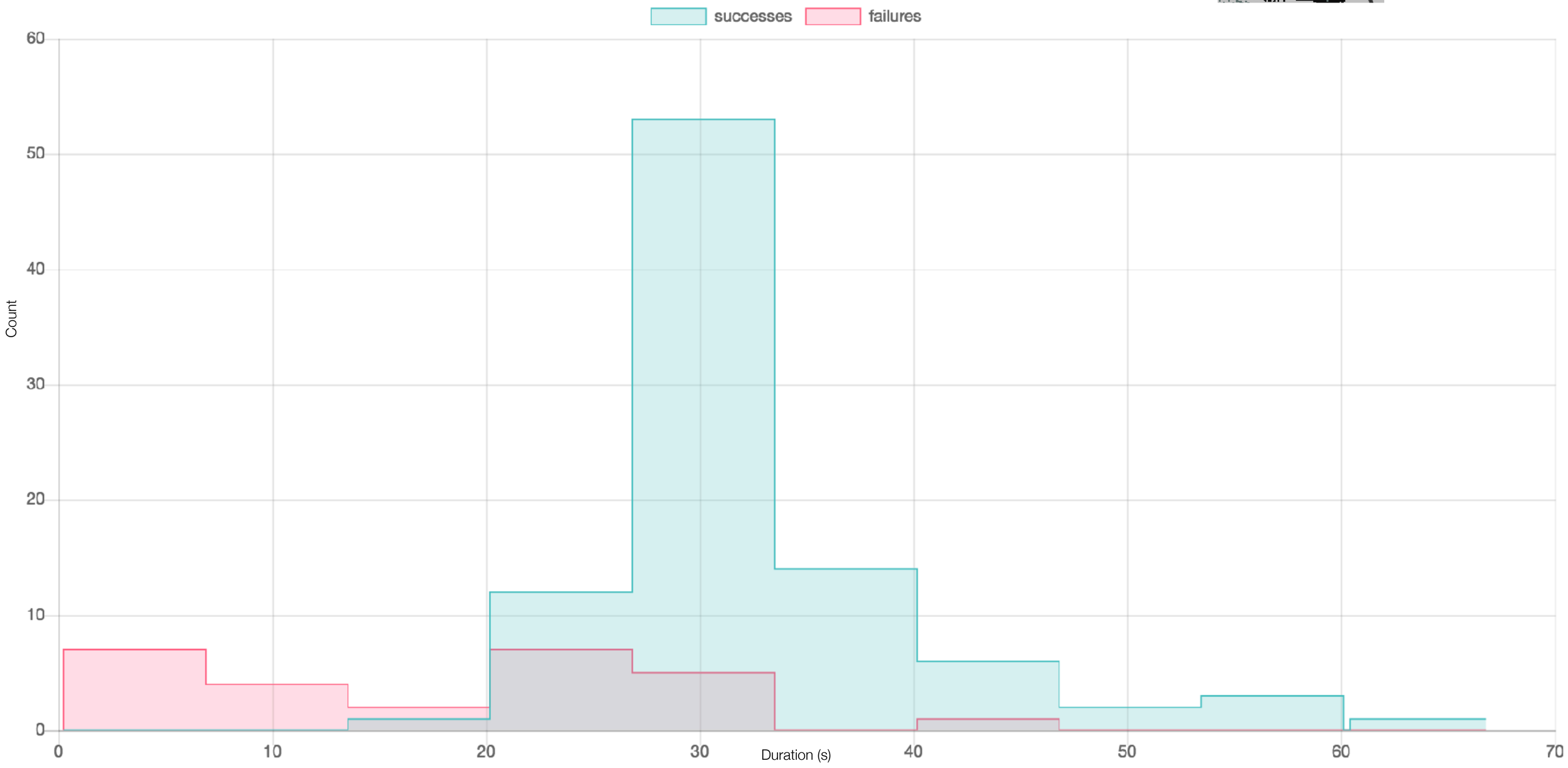
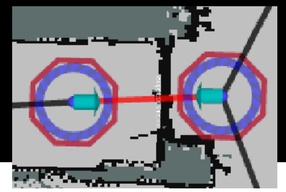
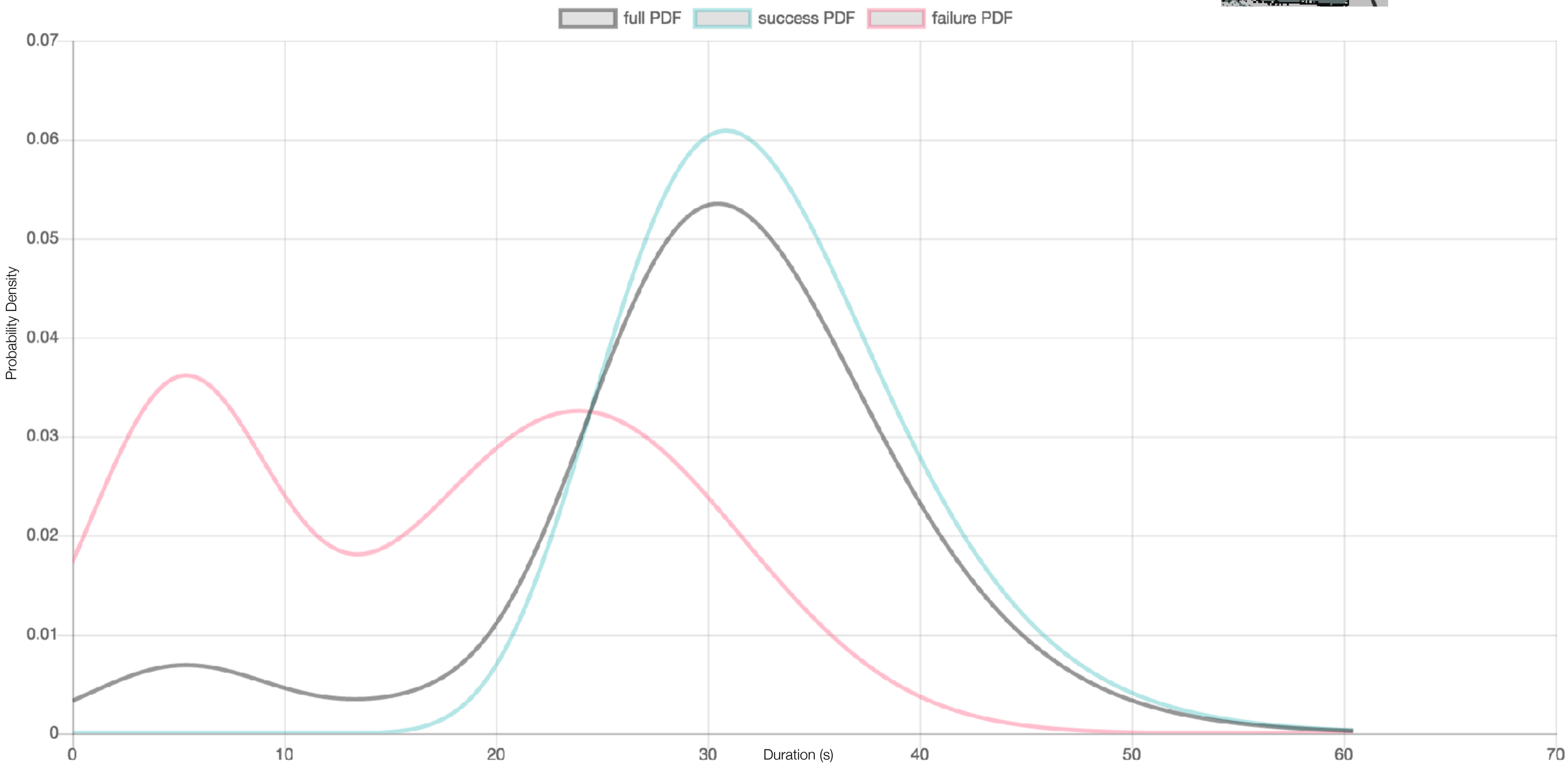
Learning from long-term experience





Learning from long-term experience





JupyterLab

localhost:8888/lab

File Edit View Run Kernel Tabs Settings Help

robot_navigation_statistics. | tsc_y3_nav_stats.csv

Delimiter: ,

	date_started	status	origin	target	final_node	edge_id	date_started	date_finished	date_at_node	operation_time	time_to_waypoint	status_bin
1	2016-05-23 18:45:47	success	WayPoint46	WayPoint39	WayPoint39	WayPoint46_WayPoint39	2016-05-23 18:45:47	2016-05-23 18:46:02	2016-05-23 18:45:56	14.547985	5.41281	1
2	2016-05-23 18:46:13	success	WayPoint39	WayPoint38	WayPoint38	WayPoint39_WayPoint38	2016-05-23 18:46:13	2016-05-23 18:46:21	2016-05-23 18:46:20	7.208904	0.34203	1
3	2016-05-23 18:46:21	success	WayPoint38	WayPoint52	WayPoint52	WayPoint38_WayPoint52	2016-05-23 18:46:21	2016-05-23 18:47:08	2016-05-23 18:47:02	46.988428	5.680518	1
4	2016-05-23 18:47:31	success	WayPoint49	WayPoint47	WayPoint47	WayPoint49_WayPoint47	2016-05-23 18:47:31	2016-05-23 18:47:58	2016-05-23 18:47:52	26.911676	6.033085	1
5	2016-05-23 18:48:30	success	WayPoint46	WayPoint41	WayPoint41	WayPoint46_WayPoint41	2016-05-23 18:48:30	2016-05-23 18:48:47	2016-05-23 18:48:41	17.215546	5.619761	1
6	2016-05-23 18:49:18	success	WayPoint43	WayPoint36	WayPoint36	WayPoint43_WayPoint36	2016-05-23 18:49:18	2016-05-23 18:49:34	2016-05-23 18:49:34	16.739608	0.343646	1
7	2016-05-23 18:49:54	fatal	WayPoint35	WayPoint34	none	WayPoint35_WayPoint34	2016-05-23 18:49:54	2016-05-23 18:51:00	2016-05-23 18:49:54	66.146298	0.0	0
8	2016-05-23 18:51:54	success	WayPoint34	WayPoint55	WayPoint55	WayPoint34_WayPoint55	2016-05-23 18:51:54	2016-05-23 18:52:11	2016-05-23 18:52:11	16.575059	0.337496	1
9	2016-05-23 18:52:24	success	WayPoint57	WayPoint58	WayPoint58	WayPoint57_WayPoint58	2016-05-23 18:52:24	2016-05-23 18:52:39	2016-05-23 18:52:35	14.809949	3.810772	1
10	2016-05-23 18:53:01	success	WayPoint57	WayPoint65	WayPoint65	WayPoint57_WayPoint65	2016-05-23 18:53:01	2016-05-23 18:53:24	2016-05-23 18:53:17	23.378326	6.993323	1
11	2016-05-23 18:54:17	success	WayPoint33	WayPoint31	WayPoint31	WayPoint33_WayPoint31	2016-05-23 18:54:17	2016-05-23 18:54:34	2016-05-23 18:54:29	16.951891	5.180523	1
12	2016-05-23 18:55:12	success	WayPoint30	WayPoint29	WayPoint29	WayPoint30_WayPoint29	2016-05-23 18:55:12	2016-05-23 18:55:21	2016-05-23 18:55:21	9.894465	0.336804	1
13	2016-05-23 18:55:43	success	WayPoint28	WayPoint25	WayPoint25	WayPoint28_WayPoint25	2016-05-23 18:55:43	2016-05-23 18:55:49	2016-05-23 18:55:48	5.893076	0.342736	1
14	2016-05-23 18:56:08	success	WayPoint24	WayPoint22	WayPoint22	WayPoint24_WayPoint22	2016-05-23 18:56:08	2016-05-23 18:56:21	2016-05-23 18:56:20	12.473608	0.341761	1
15	2016-05-23 18:56:35	success	WayPoint18	WayPoint17	WayPoint17	WayPoint18_WayPoint17	2016-05-23 18:56:35	2016-05-23 18:57:09	2016-05-23 18:57:01	33.972627	7.703304	1
16	2016-05-23 18:57:49	success	WayPoint16	WayPoint1	WayPoint1	WayPoint16_WayPoint1	2016-05-23 18:57:49	2016-05-23 18:58:04	2016-05-23 18:58:04	14.926991	0.351873	1
17	2016-05-23 18:58:24	success	Station1	WayPoint4	WayPoint4	Station1_WayPoint4	2016-05-23 18:58:24	2016-05-23 18:58:35	2016-05-23 18:58:35	11.299606	0.346172	1
18	2016-05-23 18:58:43	success	WayPoint5	WayPoint8	WayPoint8	WayPoint5_WayPoint8	2016-05-23 18:58:43	2016-05-23 18:58:52	2016-05-23 18:58:52	8.947915	0.353658	1
19	2016-05-23 18:58:52	success	WayPoint8	WayPoint9	WayPoint9	WayPoint8_WayPoint9	2016-05-23 18:58:52	2016-05-23 18:59:00	2016-05-23 18:59:00	7.442625	0.343227	1
20	2016-05-23 18:59:11	fatal	WayPoint9	WayPoint13	WayPoint9	WayPoint9_WayPoint13	2016-05-23 18:59:11	2016-05-23 18:59:13	2016-05-23 18:59:11	2.457449	0.0	0
21	2016-05-23 18:59:20	success	WayPoint9	WayPoint10	WayPoint10	WayPoint9_WayPoint10	2016-05-23 18:59:20	2016-05-23 18:59:33	2016-05-23 18:59:27	13.955448	6.092871	1
22	2016-05-23 19:03:28	success	WayPoint14	WayPoint15	WayPoint15	WayPoint14_WayPoint15	2016-05-23 19:03:28	2016-05-23 19:04:14	2016-05-23 19:04:08	45.953335	5.998226	1
23	2016-05-23 19:05:33	success	WayPoint14	WayPoint4	WayPoint4	WayPoint14_WayPoint4	2016-05-23 19:05:33	2016-05-23 19:05:49	2016-05-23 19:05:48	16.138392	0.340768	1
24	2016-05-23 19:06:00	success	WayPoint1	WayPoint16	WayPoint16	WayPoint1_WayPoint16	2016-05-23 19:06:00	2016-05-23 19:06:13	2016-05-23 19:06:13	12.841951	0.356403	1
25	2016-05-23 19:06:19	success	WayPoint19	WayPoint18	WayPoint18	WayPoint19_WayPoint18	2016-05-23 19:06:19	2016-05-23 19:06:27	2016-05-23 19:06:27	8.322847	0.344295	1
26	2016-05-23 19:06:40	success	WayPoint22	WayPoint25	WayPoint25	WayPoint22_WayPoint25	2016-05-23 19:06:40	2016-05-23 19:06:59	2016-05-23 19:06:59	18.828002	0.344505	1
27	2016-05-23 19:07:10	success	WayPoint27	WayPoint30	WayPoint30	WayPoint27_WayPoint30	2016-05-23 19:07:10	2016-05-23 19:07:28	2016-05-23 19:07:24	18.792159	3.900862	1
28	2016-05-23 19:08:09	fatal	WayPoint31	WayPoint33	WayPoint33	WayPoint31_WayPoint33	2016-05-23 19:08:09	2016-05-23 19:08:44	2016-05-23 19:08:39	35.000216	4.907587	0
29	2016-05-23 19:08:45	fatal	WayPoint33	WayPoint34	WayPoint34	WayPoint33_WayPoint34	2016-05-23 19:08:45	2016-05-23 19:09:51	2016-05-23 19:09:47	65.718012	4.229726	0
30	2016-05-23 19:10:11	fatal	WayPoint36	WayPoint43	WayPoint43	WayPoint36_WayPoint43	2016-05-23 19:10:11	2016-05-23 19:10:28	2016-05-23 19:10:28	17.331293	0.349056	0
31	2016-05-23 20:12:30	success	WayPoint41	WayPoint46	WayPoint46	WayPoint41_WayPoint46	2016-05-23 20:12:30	2016-05-23 20:12:43	2016-05-23 20:12:42	12.479186	0.358479	1
32	2016-05-23 20:15:45	fatal	WayPoint38	WayPoint46	WayPoint38	WayPoint38_WayPoint46	2016-05-23 20:15:45	2016-05-23 20:15:53	2016-05-23 20:15:45	7.98709	0.0	0
33	2016-05-23 20:17:39	success	WayPoint47	WayPoint49	WayPoint49	WayPoint47_WayPoint49	2016-05-23 20:17:39	2016-05-23 20:17:56	2016-05-23 20:17:56	16.866417	0.353845	1
34	2016-05-23 20:18:24	success	WayPoint37	WayPoint36	WayPoint36	WayPoint37_WayPoint36	2016-05-23 20:18:24	2016-05-23 20:18:34	2016-05-23 20:18:34	10.449014	0.349603	1
35	2016-05-23 20:19:23	success	WayPoint57	WayPoint58	WayPoint58	WayPoint57_WayPoint58	2016-05-23 20:19:23	2016-05-23 20:19:34	2016-05-23 20:19:34	11.650591	0.358993	1