Probabilistic Planning with Formal Performance Guarantees for Mobile Service Robots

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GOAL-ORIENTED AUTONOMOUS LONG-LIVED SYSTEMS OXFORD ROBOTICS INSTITUTE

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Motivation

STRANDS

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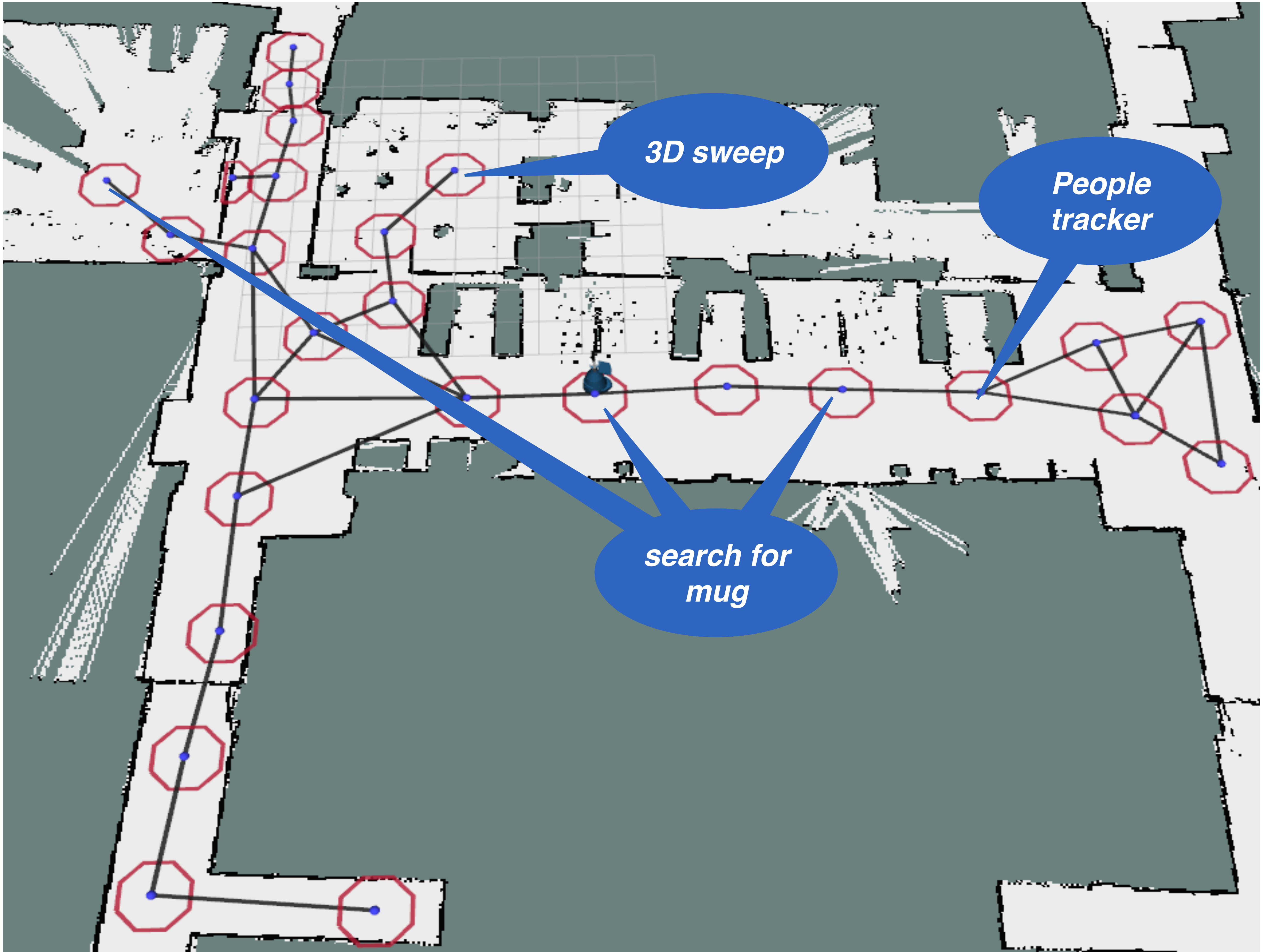
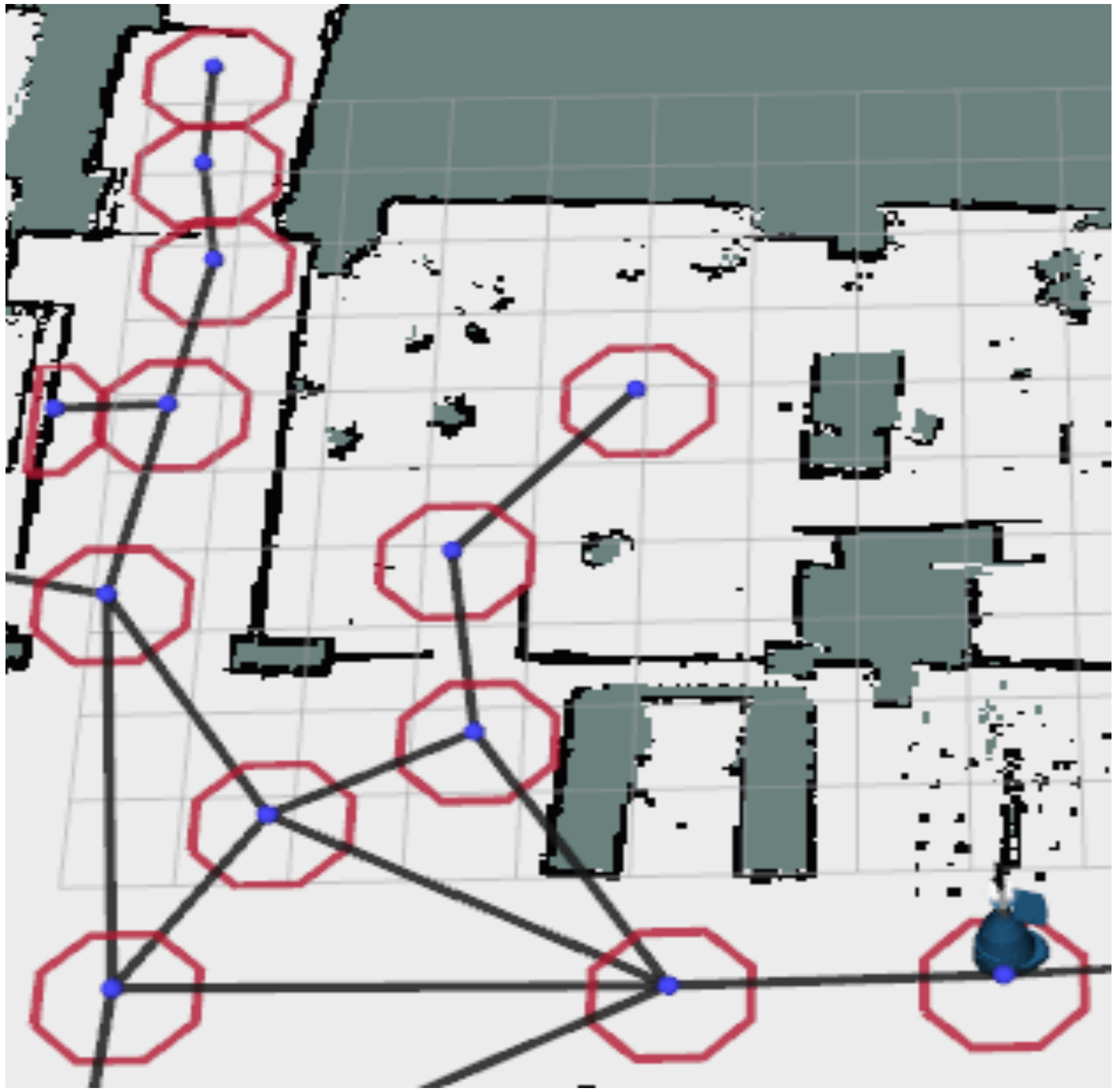
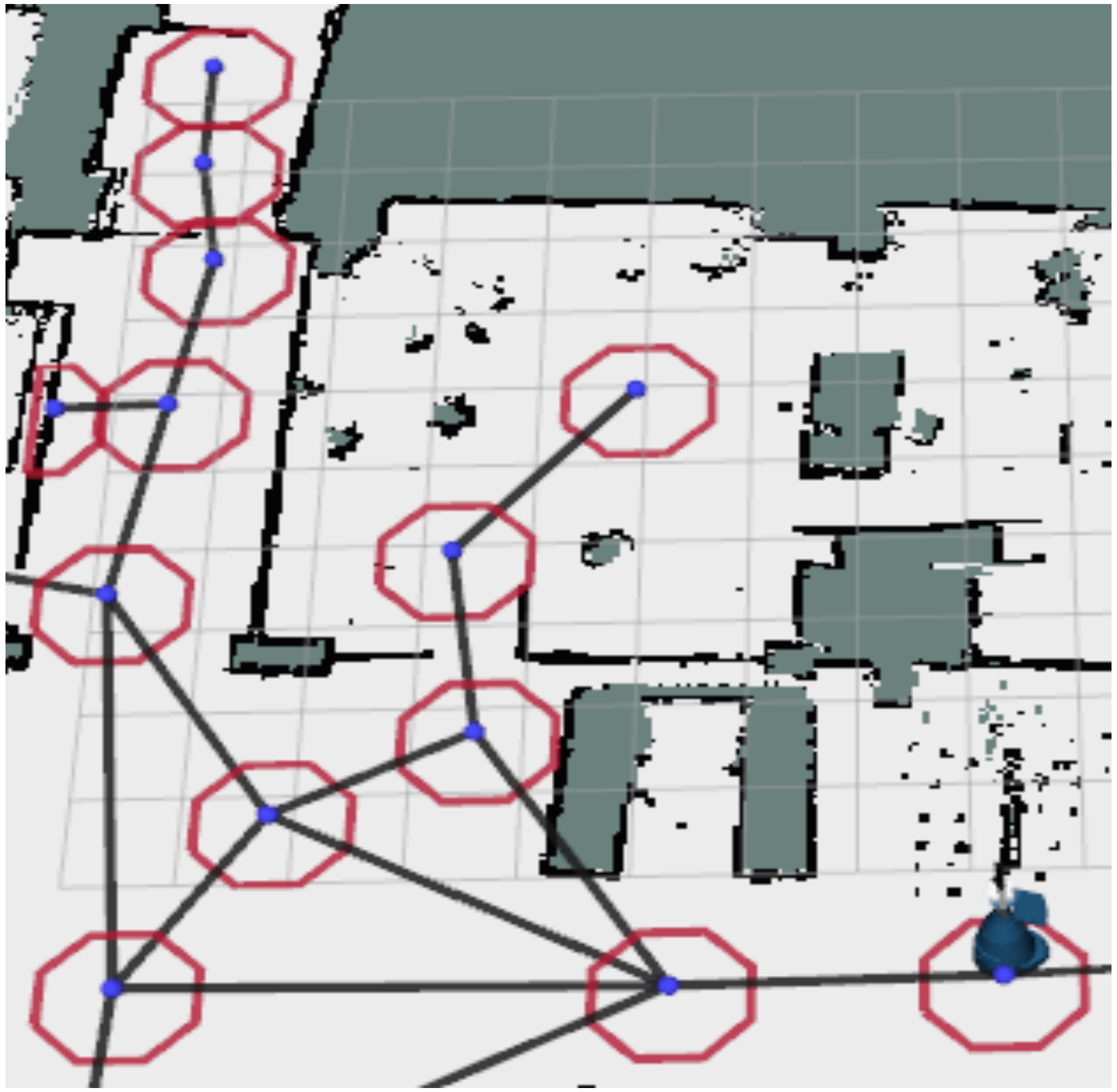


Topological Navigation



Topological Navigation

- Topological map represented as a graph where nodes correspond to relevant locations in the environment
  - Allows for navigation between locations, integrating off-the-shelf navigation with specialised navigation actions (door pass, docking, …)
  - Integrated with robust monitored navigation that allows for failure recovery and requesting human help



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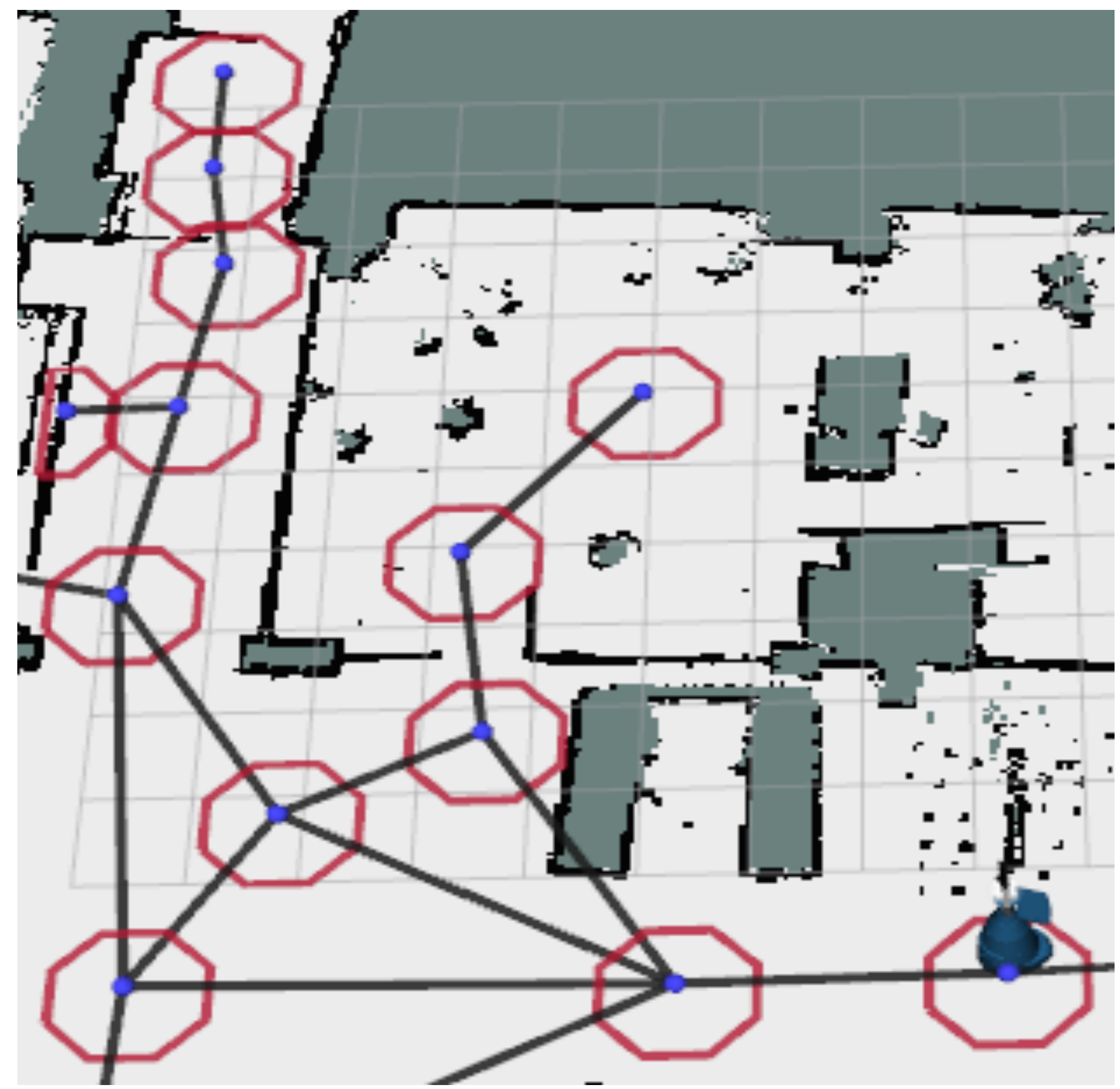
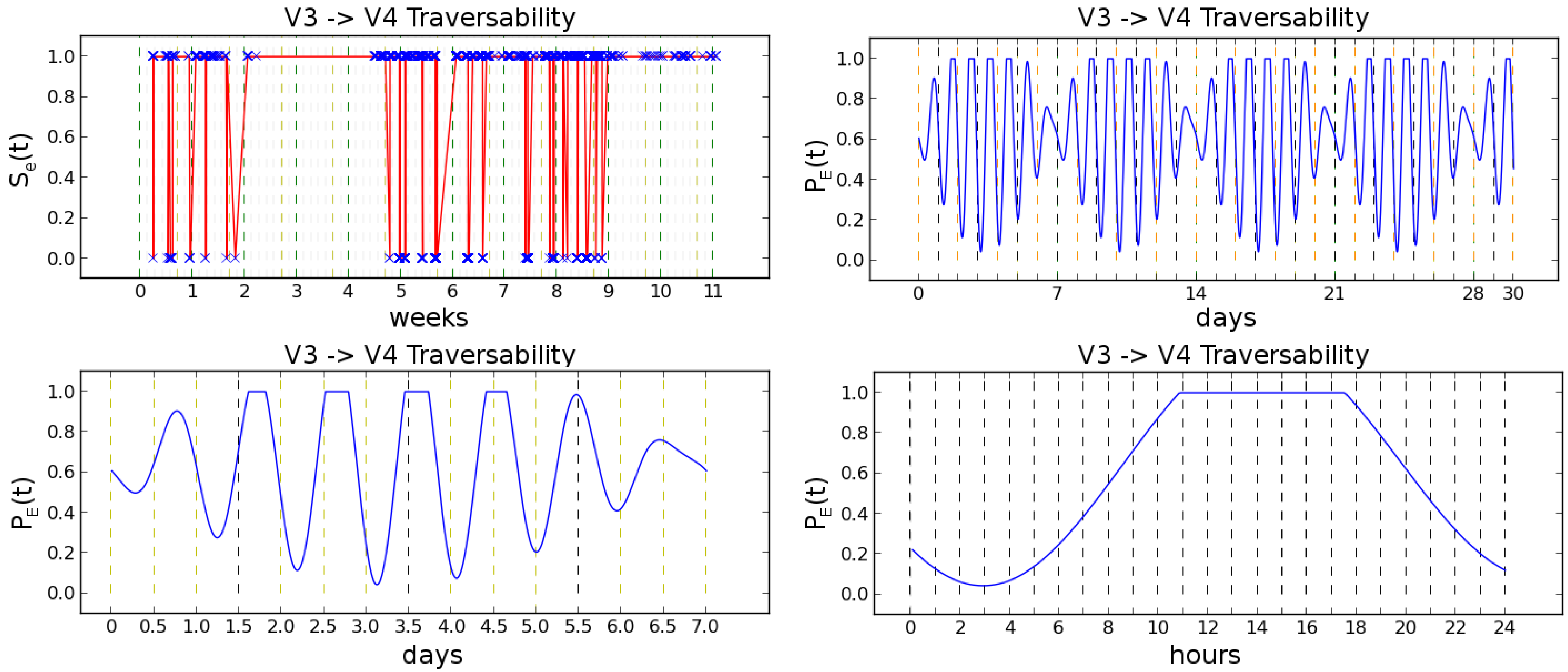
- Data is gathered for each edge traversal
  - Success/Failure
  - Navigation Time



Topological Prediction

- With the data, we can build temporal models of:
  - Probability of successful edge traversal
  - Expected time for edge traversal



Using Formal Methods

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Stochastic models encoding the inherent uncertainty of robot's actions and human populated environments

Markov Decision Processes

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Markov Decision Processes

Optimisation of meaningful real life metrics

Success Probabilities and Expected Times

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Use of formal language for intuitive and unambiguous task specifications

Linear Temporal Logic

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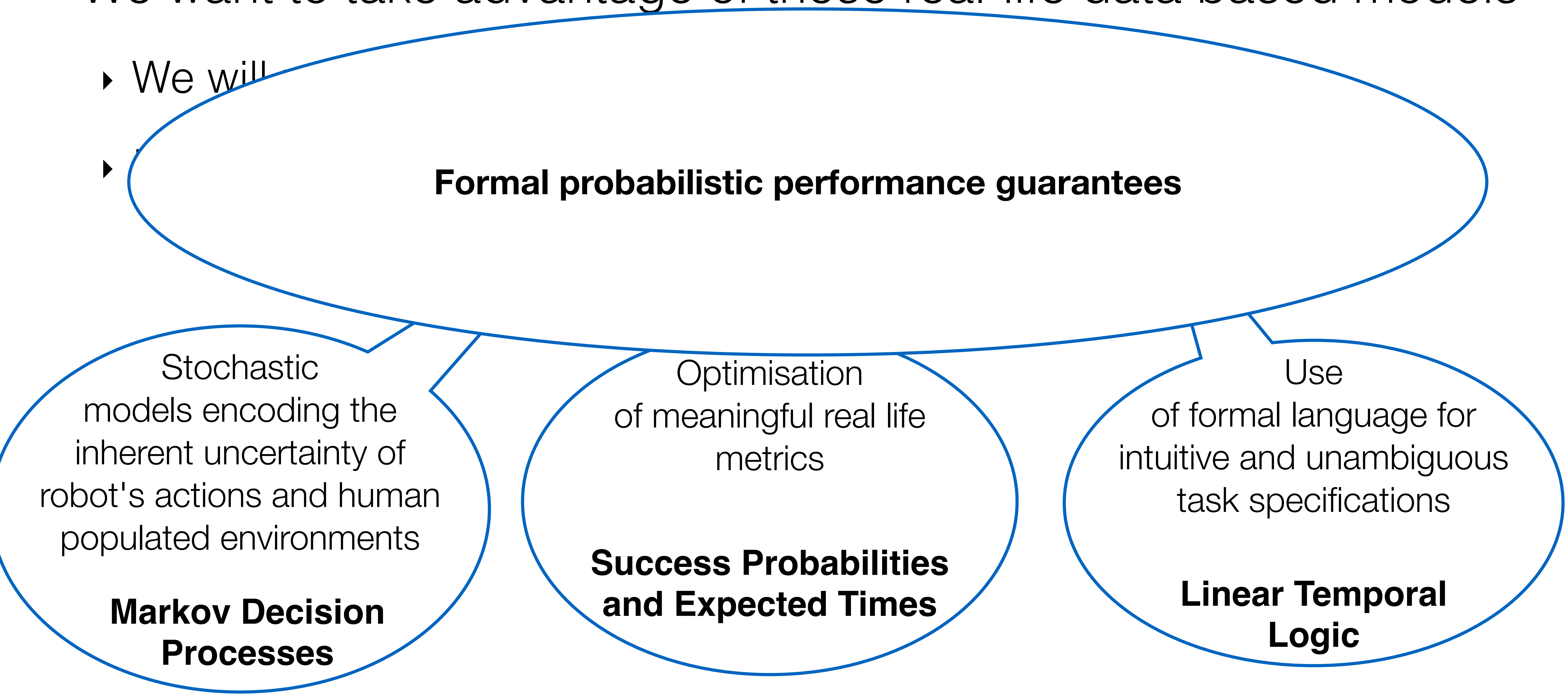
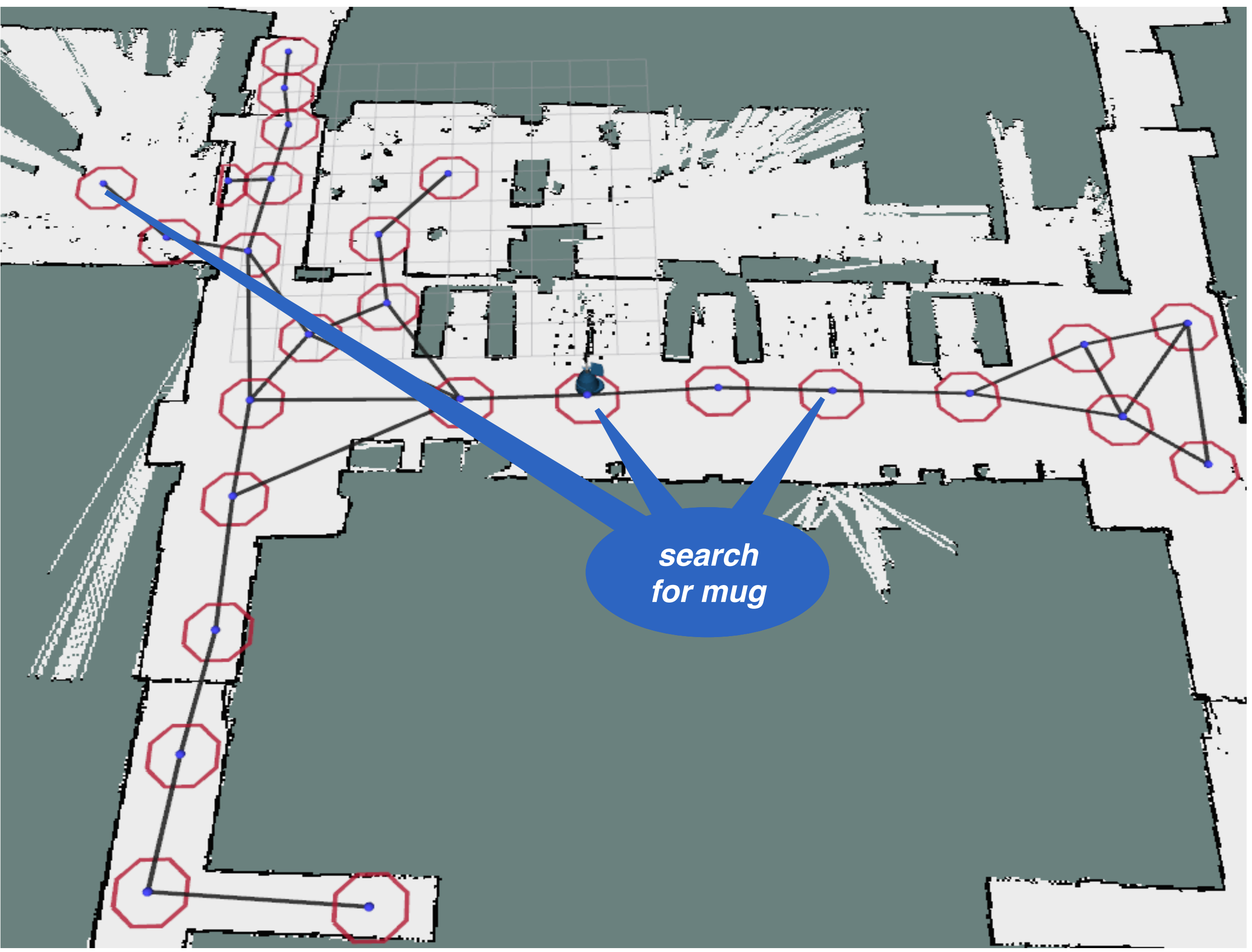
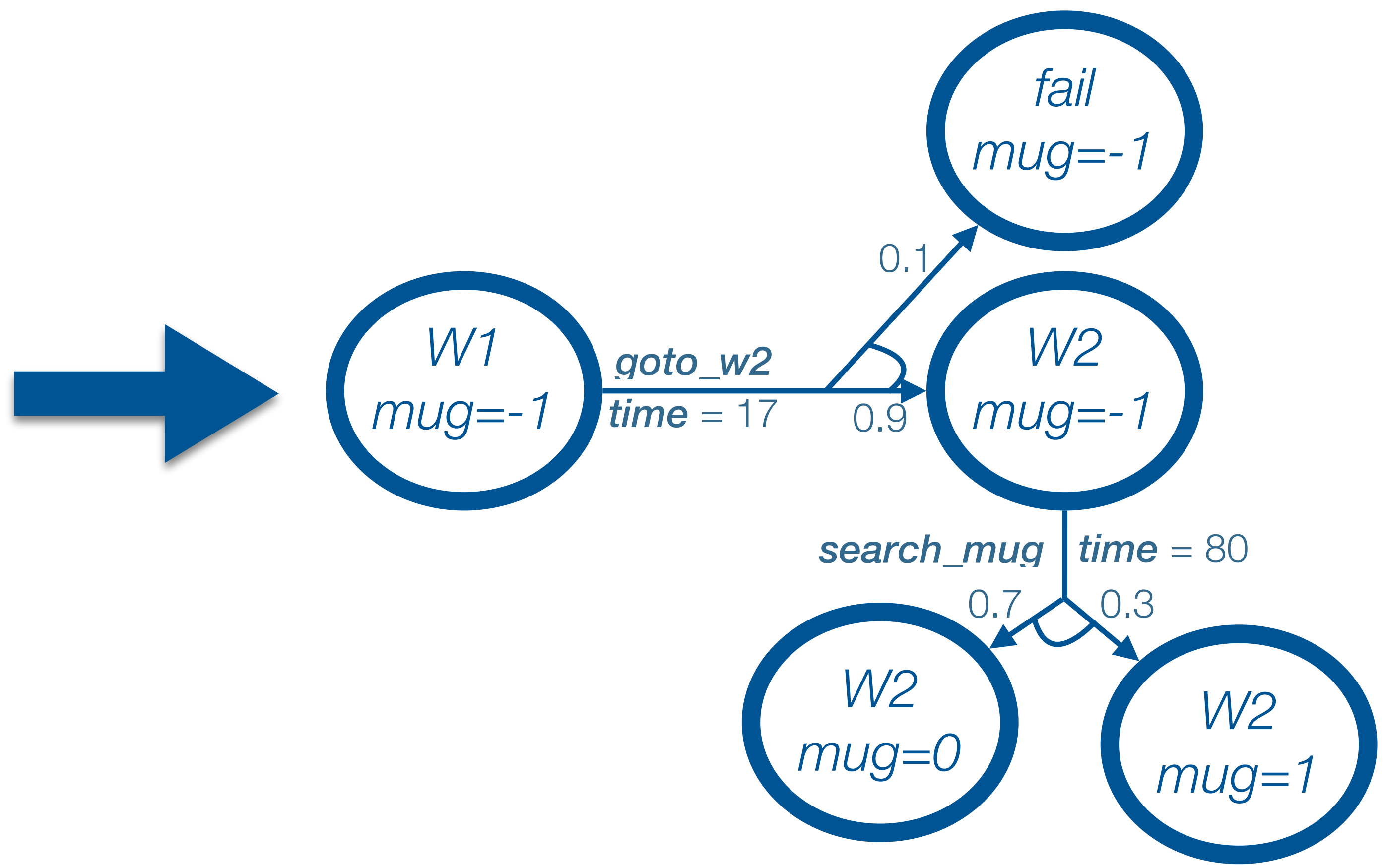


MDP Modelling





Goal Specification

Co-Safe Linear Temporal Logic

$$\varphi ::= true \mid p \mid \neg p \mid \varphi \wedge \varphi \mid \varphi \vee \varphi \mid \mathtt{X}\,\varphi \mid \mathtt{F}\,\varphi \mid \varphi\,\mathtt{U}\,\varphi, \text{ where } p \in AP.$$

“next” *“eventually”* *“until”*

“Do a metric map at waypoint 3”

$$\mathtt{F}\, metric\_map\_at\_waypoint3$$

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“next”

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“until”

“Do a metric map at waypoints 3 and 7, and make sure to navigate the edge from waypoint 3 and waypoint 4”

$$(\mathtt{F}\,metric\_map\_at\_waypoint3) \wedge (\mathtt{F}\,metric\_map\_at\_waypoint7) \wedge (\mathtt{F}(at\_waypoint3 \wedge (\mathtt{X}\,at\_waypoint4)))$$

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"Reach the living room without going through the bedroom"

$$\neg bedroom\ U\ livingroom$$

Partial Satisfiability

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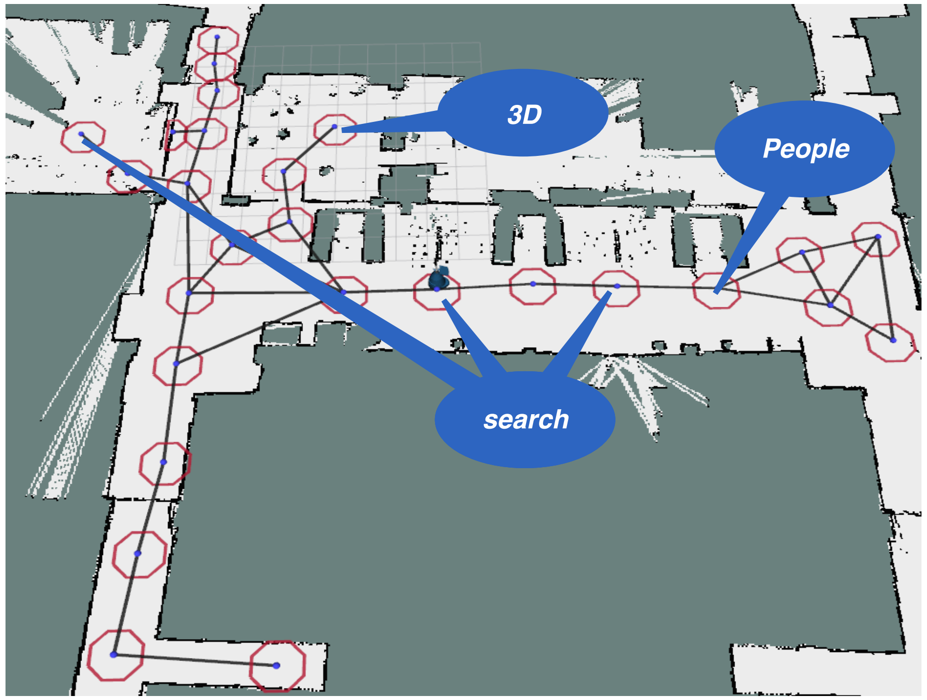
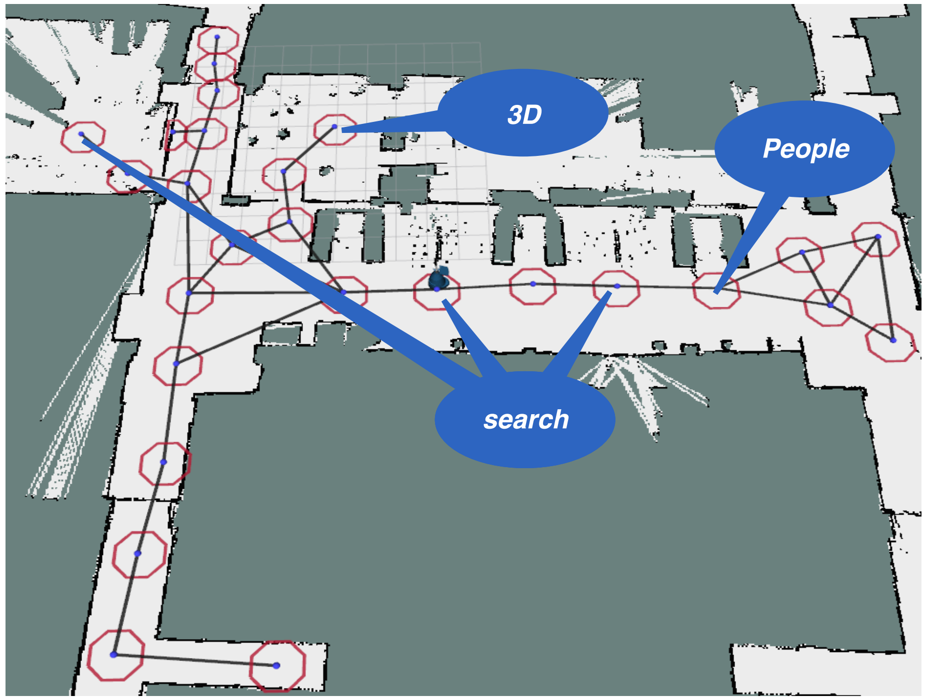


$+$ co-safe spec φ

Partial Satisfiability



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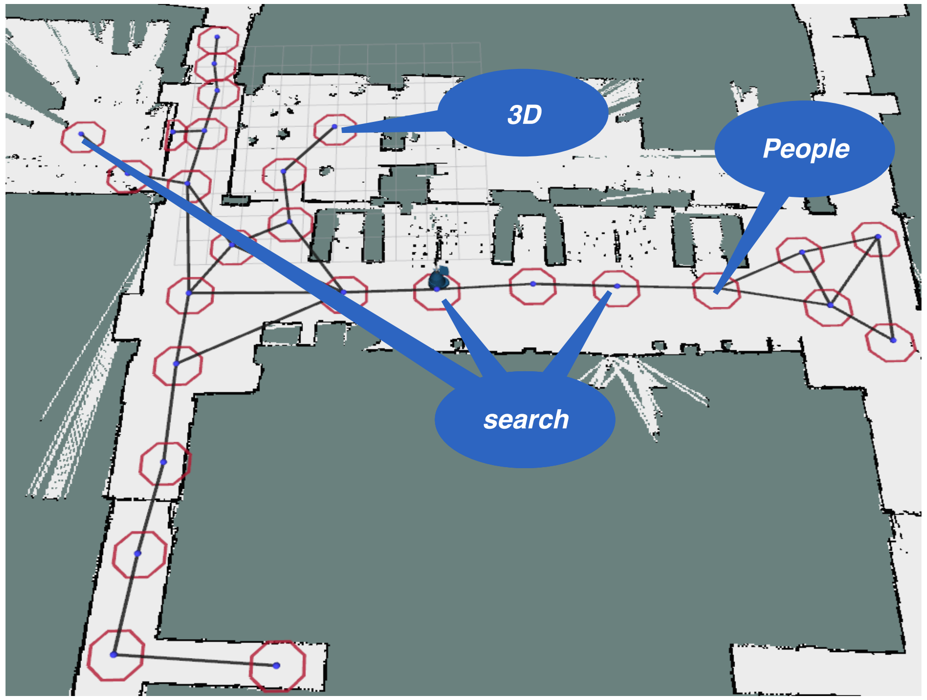

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2. **Do as much as possible:** Even when the overall spec becomes unachievable (e.g., because of a task that is to be executed behind a closed door), continue executing and achieve as much of the spec as possible

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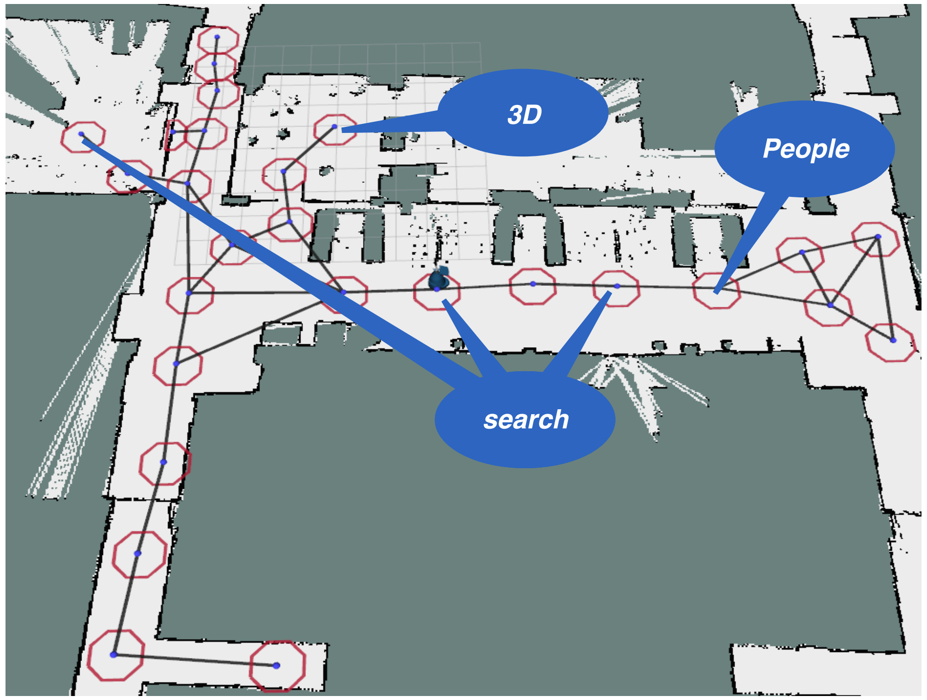

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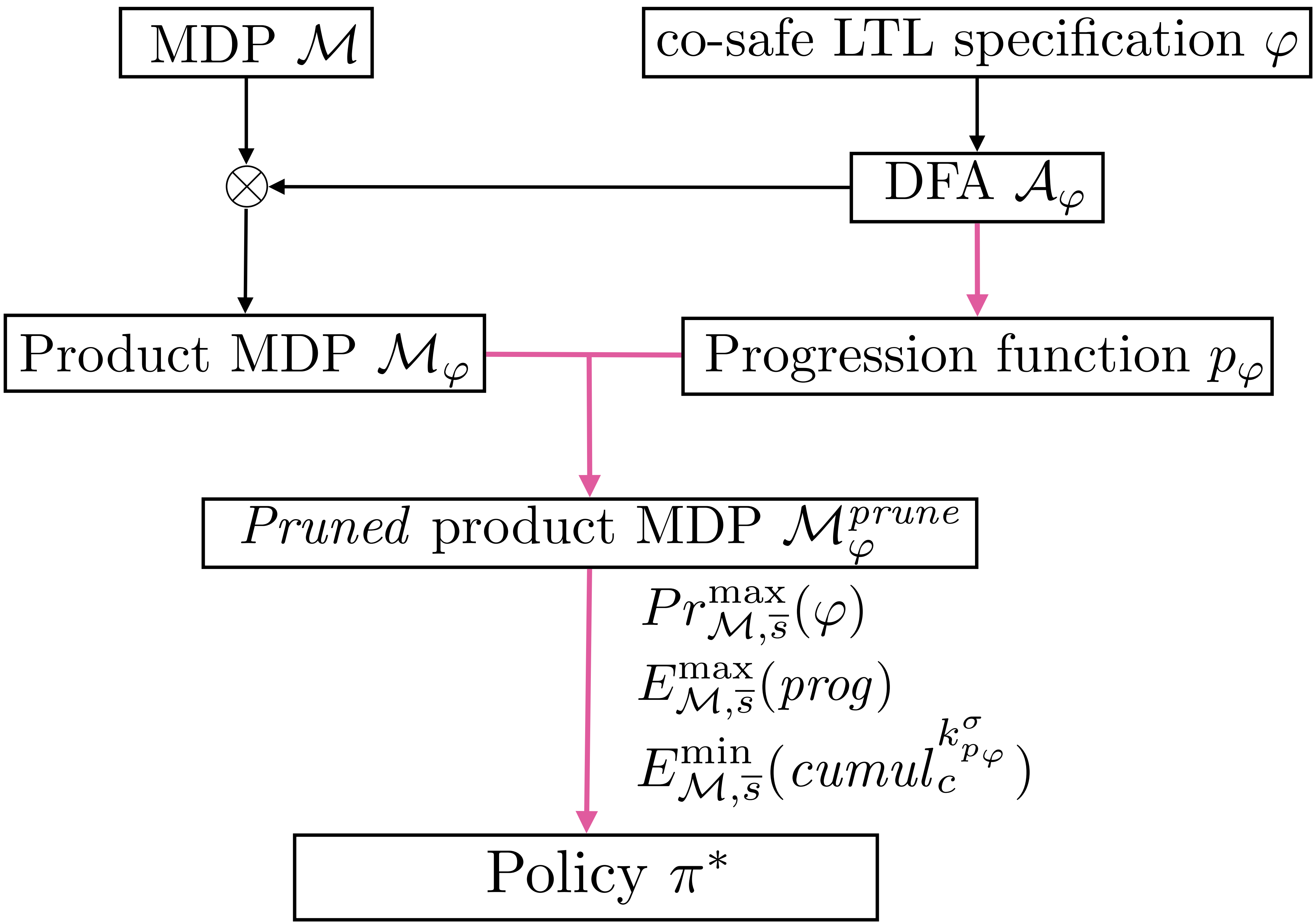
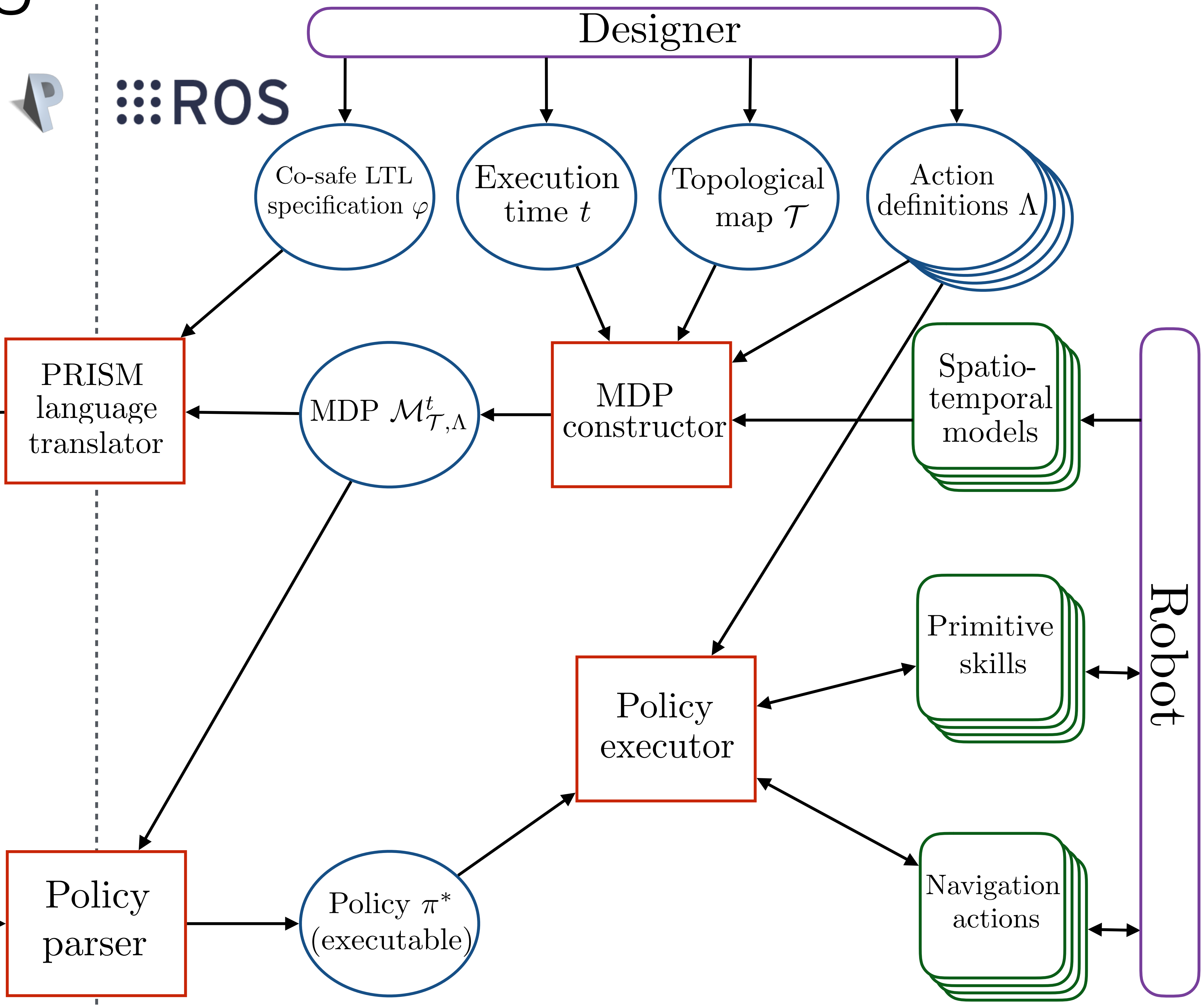
2. **Do as much as possible:** Even when the overall spec becomes unachievable (e.g., because of a task that is to be executed behind a closed door), continue executing and achieve as much of the spec as possible

3. **Be efficient:** Minimise expected time to execute the part of the task that is possible

Solution Diagram



ROS Integration



https://github.com/strands-project/strands_executive/tree/kinetic-devel/mdp_plan_exec

Conclusions

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- Contributions:
  - **Stochastic modelling** of service robot from long term deployment data
  - **Goals specified** in rich language, namely co-safe LTL
  - **Novel solution technique** for partial satisfiable co-safe LTL specifications over MDPs
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- Future Work:
  - Uncertain models
  - Multi robot systems
  - Multi-objective reasoning

Thank you!

Check paper #312