ReBeT: Architecture-based Self-adaptation of Robotic Systems through Behavior Trees

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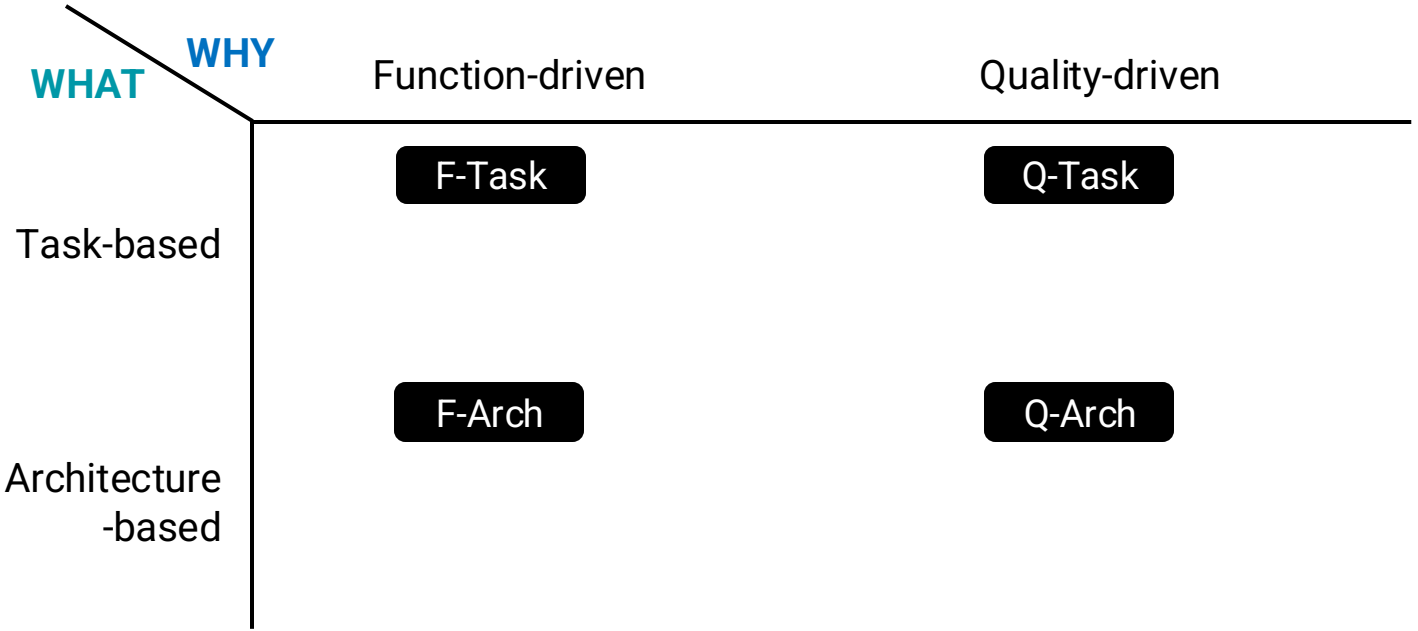
Robots need to become self-adaptive.

Background

Behavior Trees

- Kind of like a hierarchical state machine
- The tree is ‘ticked’ at the root, and this is propagated down.
- Each node is either in a state of ‘Success’, ‘Failure’ or ‘Running’
- There is quite nice library non-specific to robotics called BT.CPP

Background



Based on Alberts et al. "Software Architecture-Based Self-Adaptation in Robotics."

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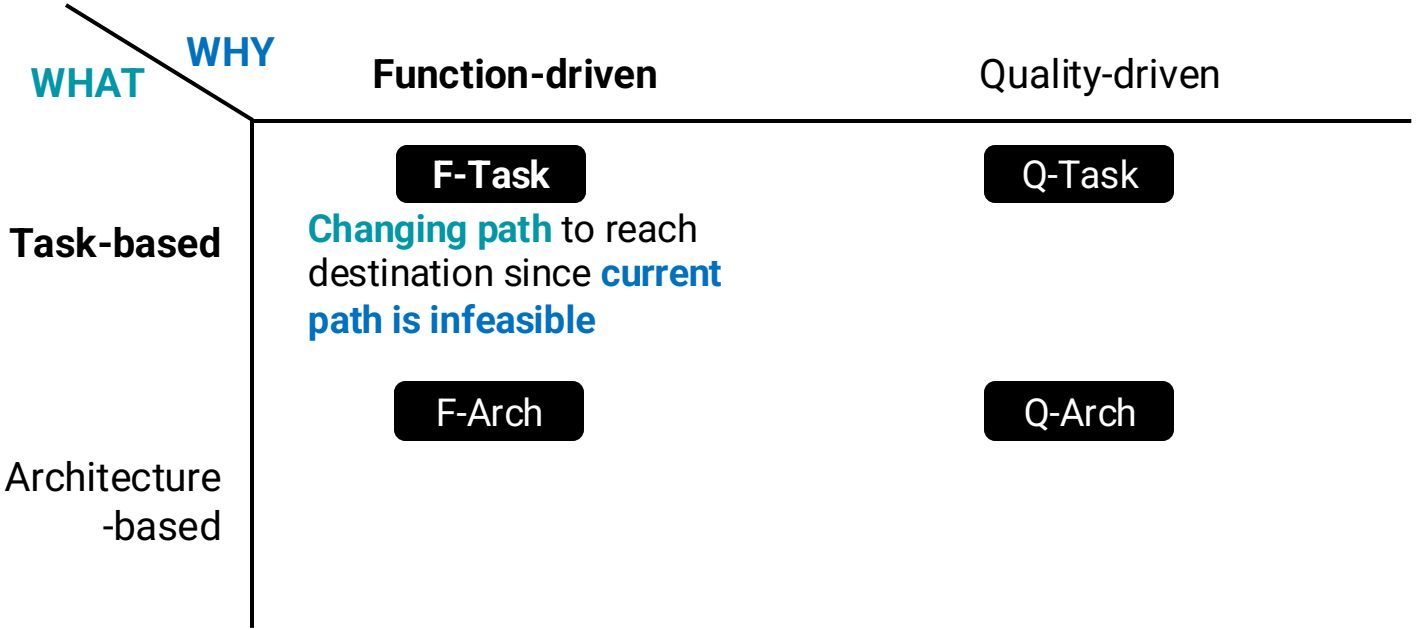

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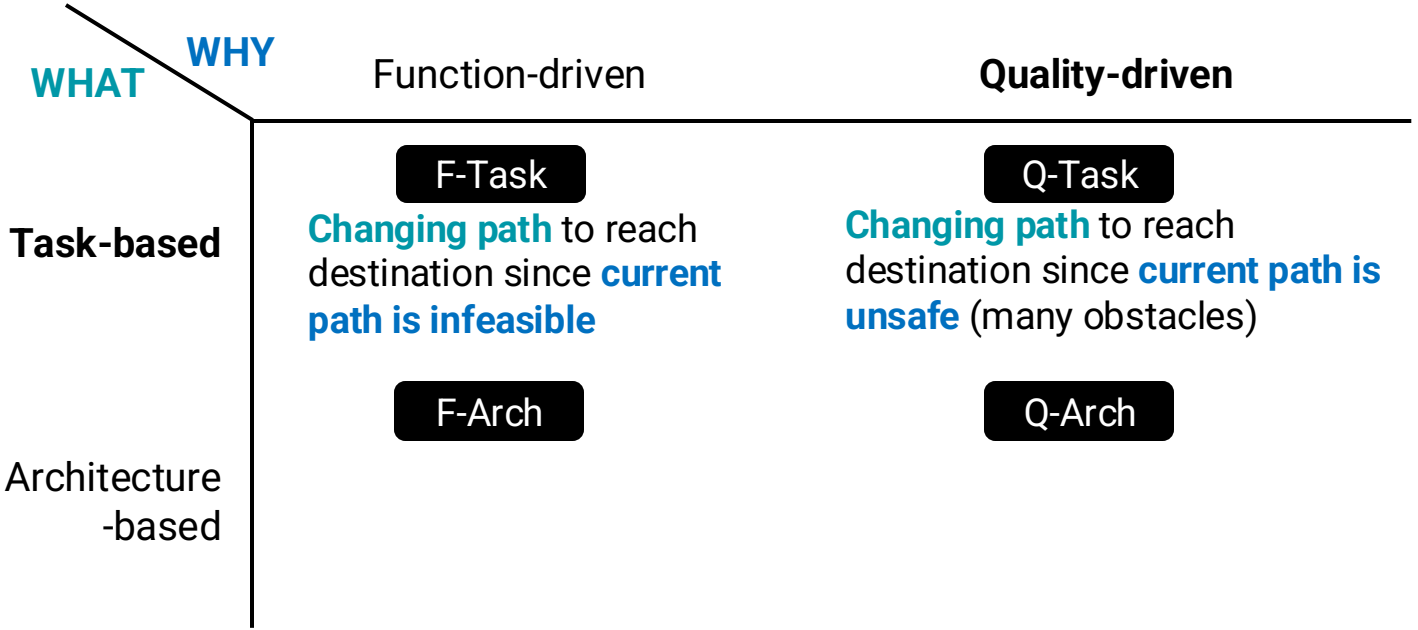

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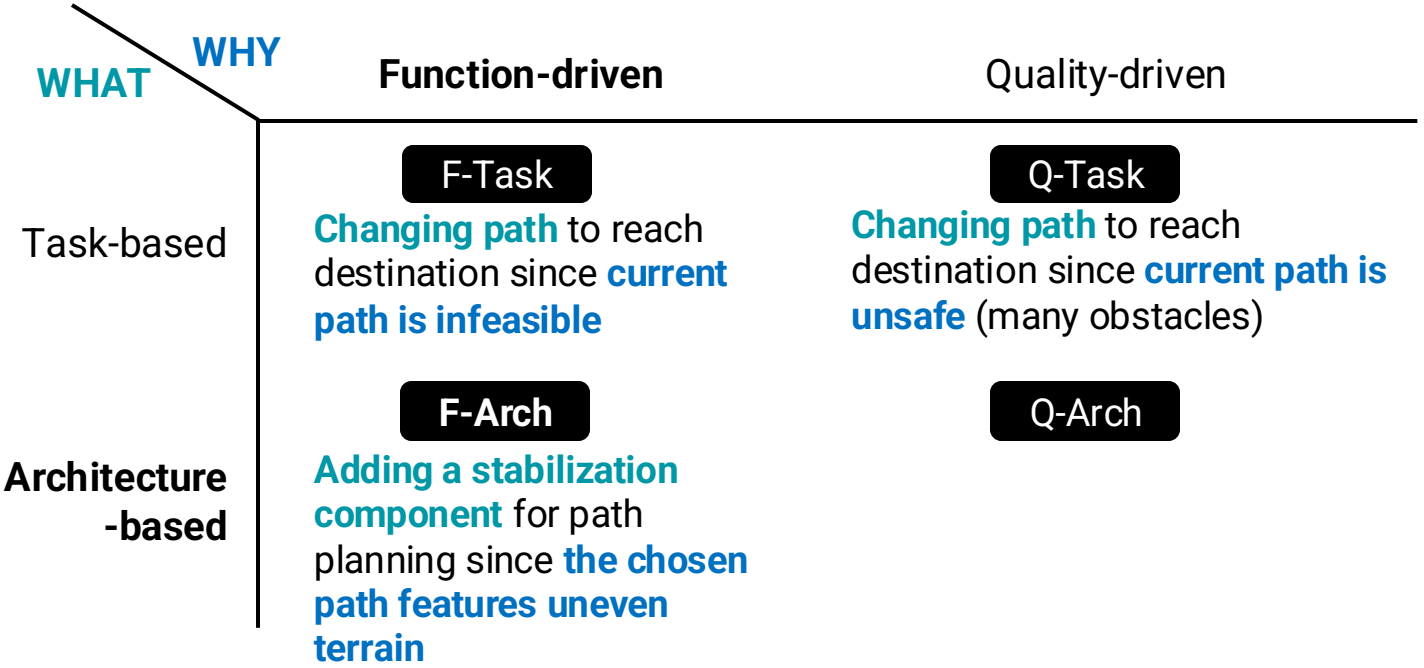

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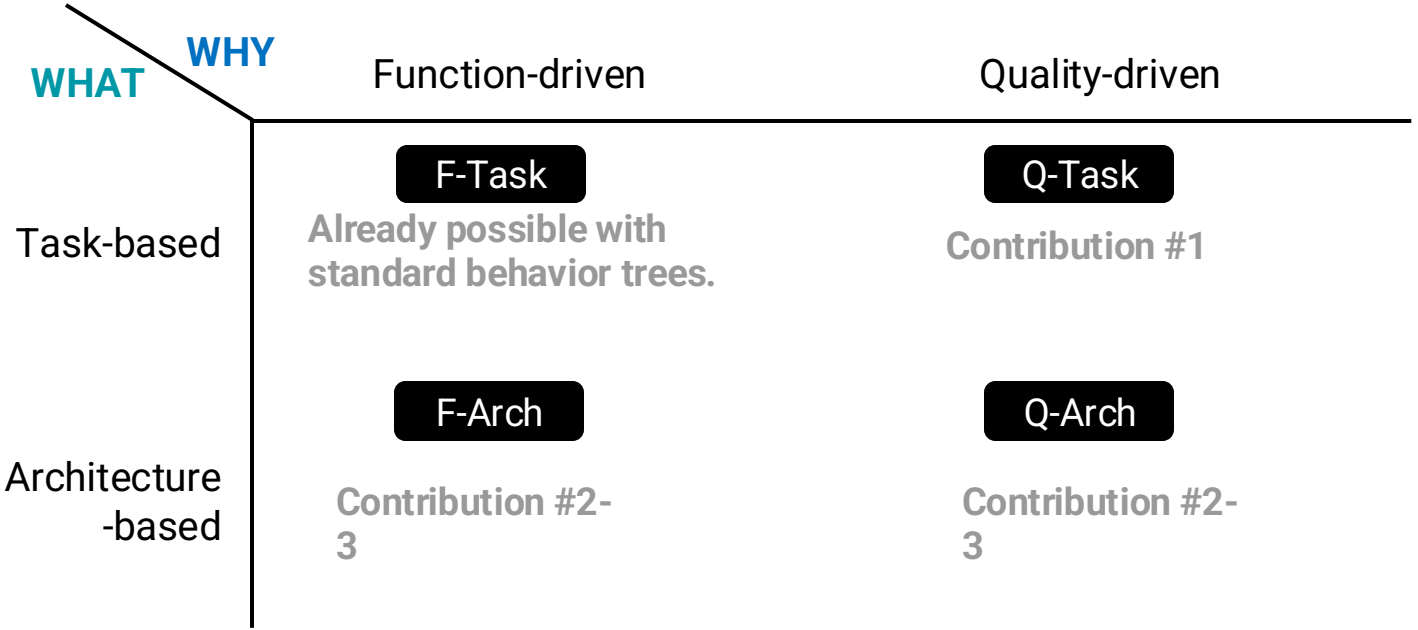
Background

WHAT \ WHY	Function-driven	**Quality-driven**
Task-based	**F-Task** **Changing path** to reach destination since **current path is infeasible**	**Q-Task** **Changing path** to reach destination since **current path is unsafe** (many obstacles)
Architecture -based	**F-Arch** **Adding a stabilization component** for path planning since **the chosen path features uneven terrain**	**Q-Arch** **Utilizing an external rather than onboard camera feed** for path planning since the **external camera is more accurate.**

Based on Alberts et al. "Software Architecture-Based Self-Adaptation in Robotics."

Background


WHY
WHAT
Function-driven
Quality-driven
Task-based
Architecture -based
F-Task
Already possible with standard behavior trees.
Q-Task
Contribution #1
F-Arch
Contribution #2-3
Q-Arch
Contribution #2-3

Standard Behavior Trees (F-Task)

Three types of BT nodes:

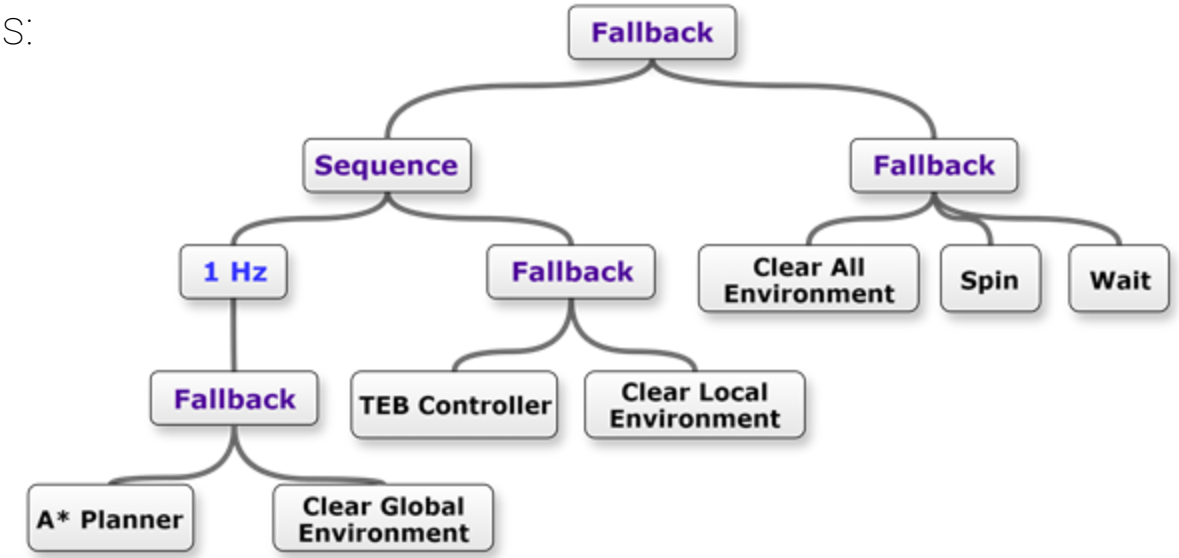
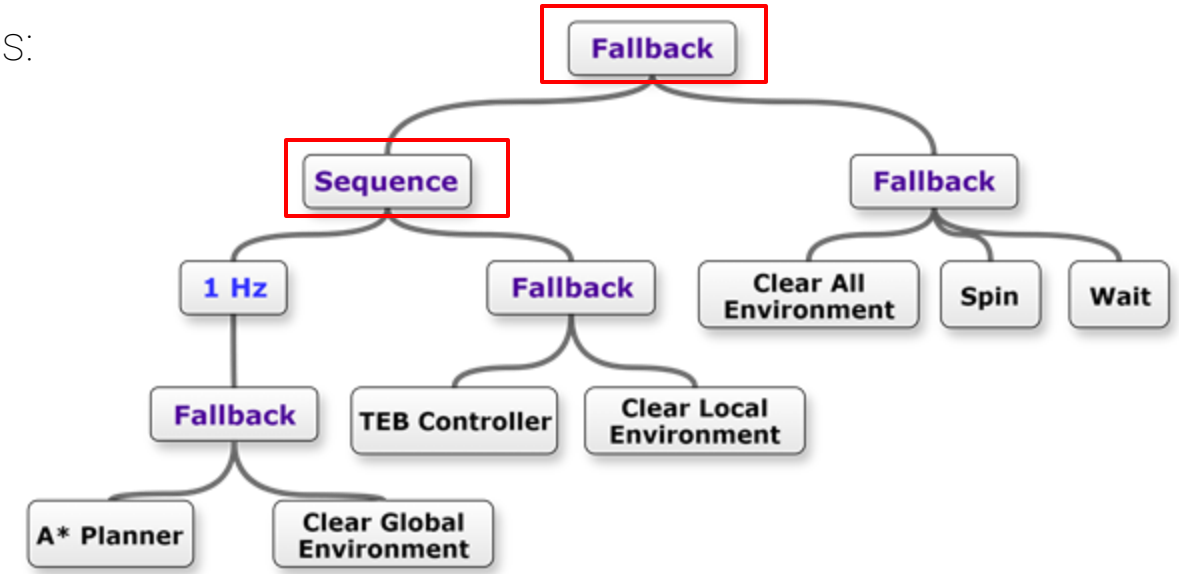


Diagram adapted from Macenski et al. "The marathon 2: A navigation system." *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2020.

Standard Behavior Trees (F-Task)

Three types of BT nodes:

- **Control**



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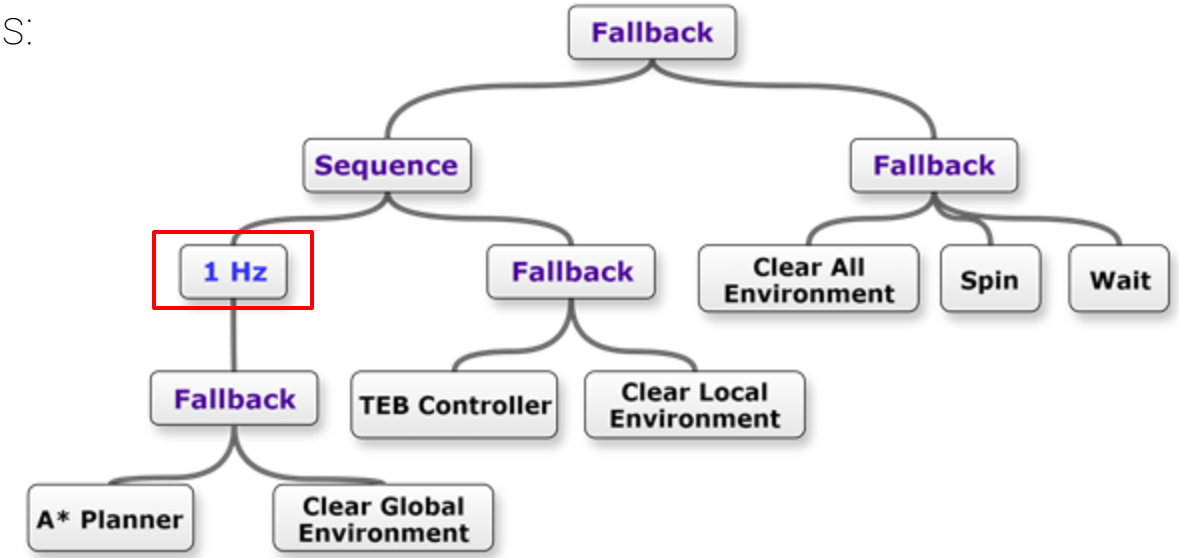
Standard Behavior Trees (F-Task)

Three types of BT nodes:

- Control
- **Decorators**



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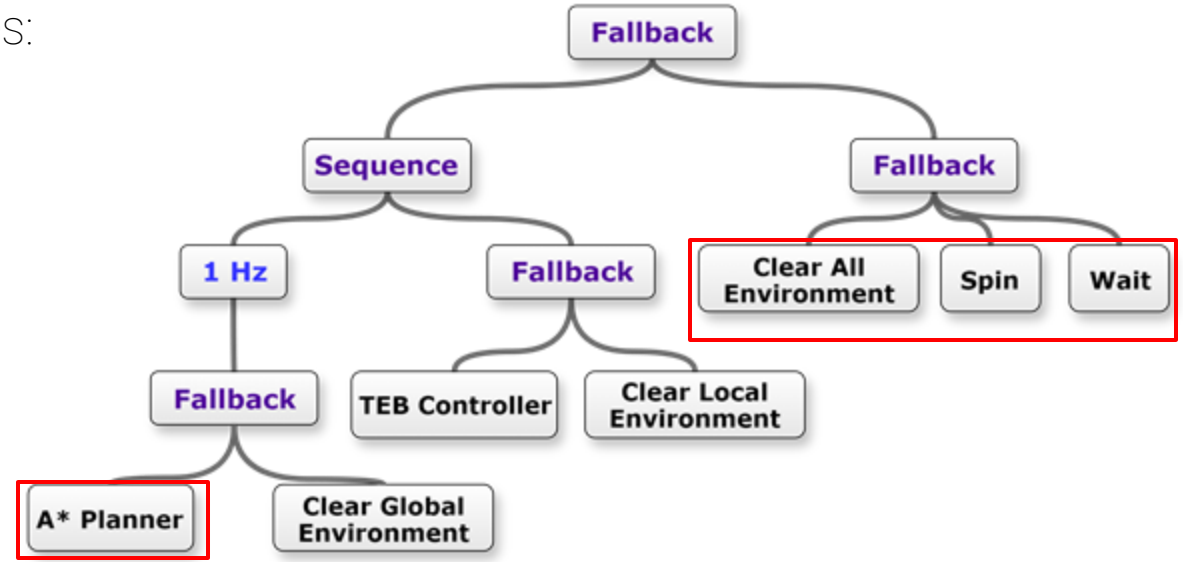
Standard Behavior Trees (F-Task)

Three types of BT nodes:

- Control
- Decorators
- **Actions**



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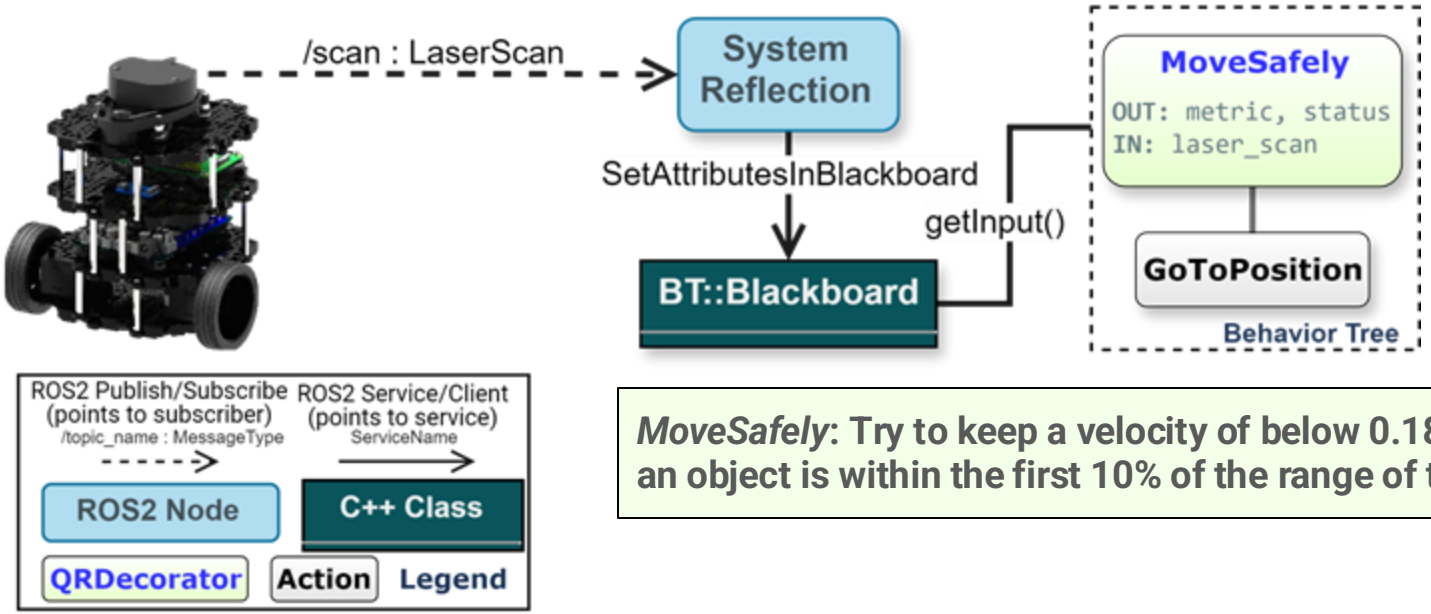
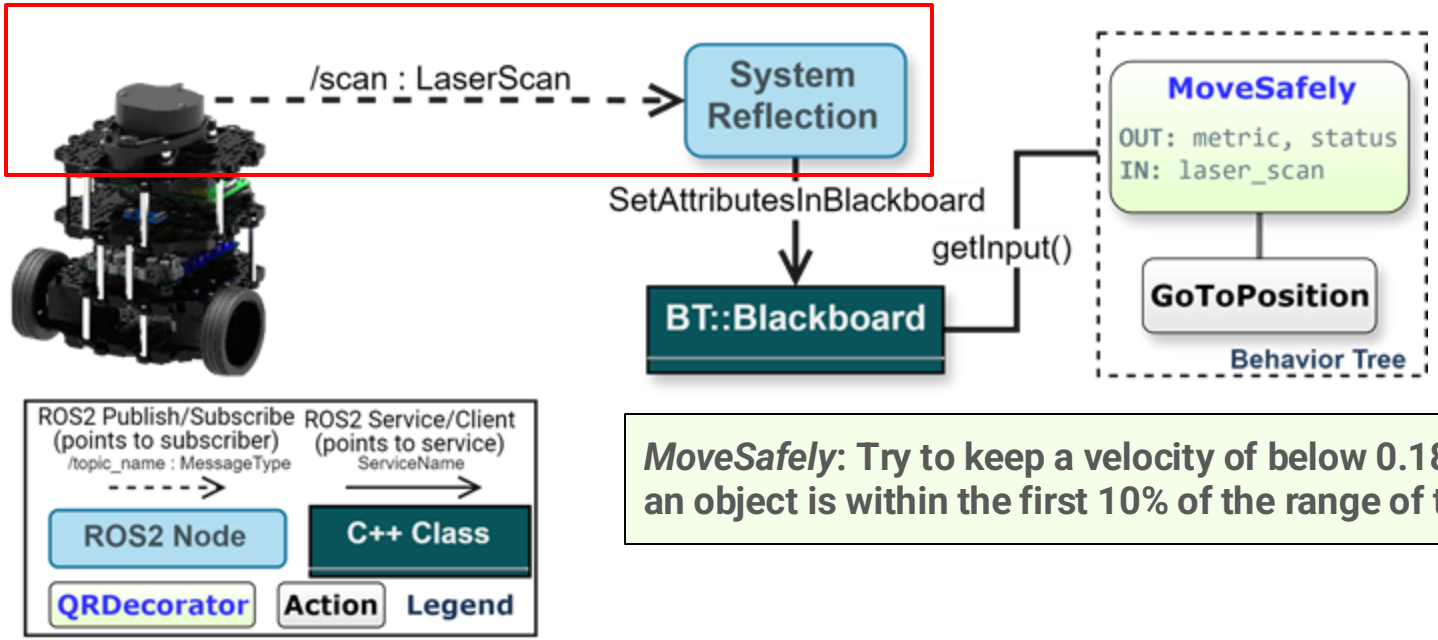
Quality Requirement Decorators (Q-Task)



***MoveSafely*: Try to keep a velocity of below 0.18m/s while an object is within the first 10% of the range of the laser.**

Quality Requirement Decorators (Q-Task)



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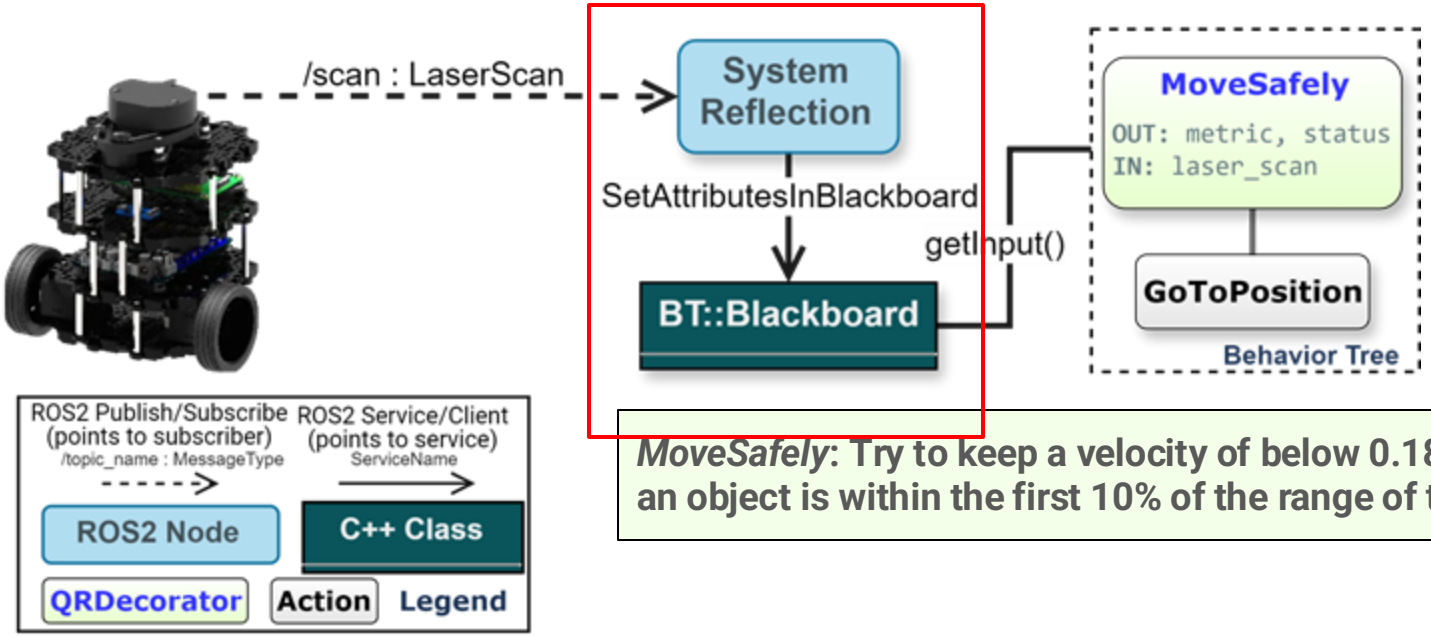

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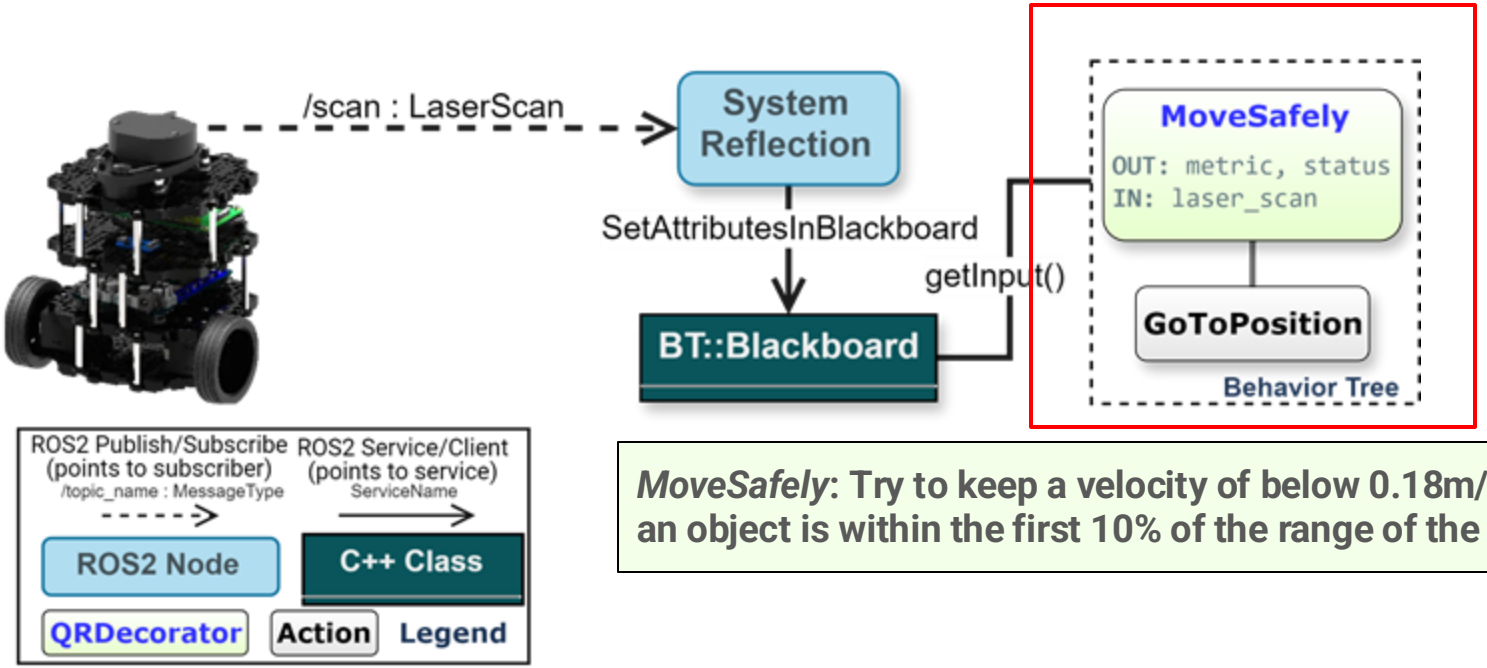
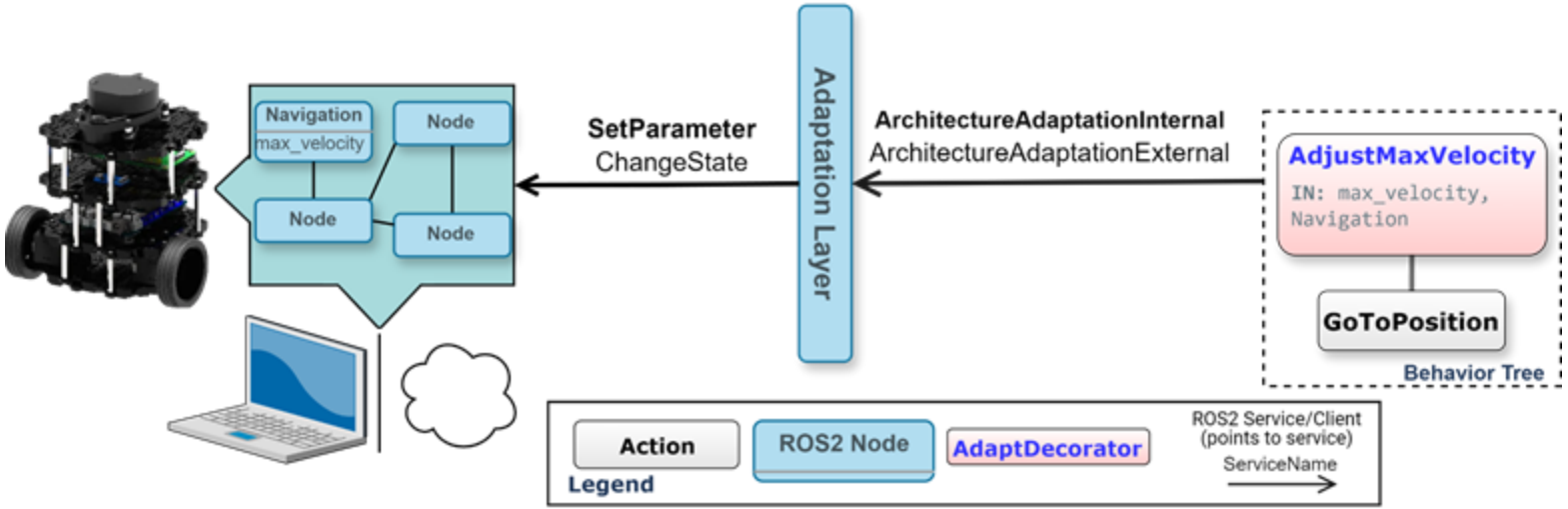


MoveSafely: Try to keep a velocity of below 0.18m/s while an object is within the first 10% of the range of the laser.

Software Architectural Adaptation (F-Arch)

We allow modifying the software architecture of a ROS2 system in several ways:

- Removal and/or addition of components
- A change in parameters of components
- A change in the interconnections of components



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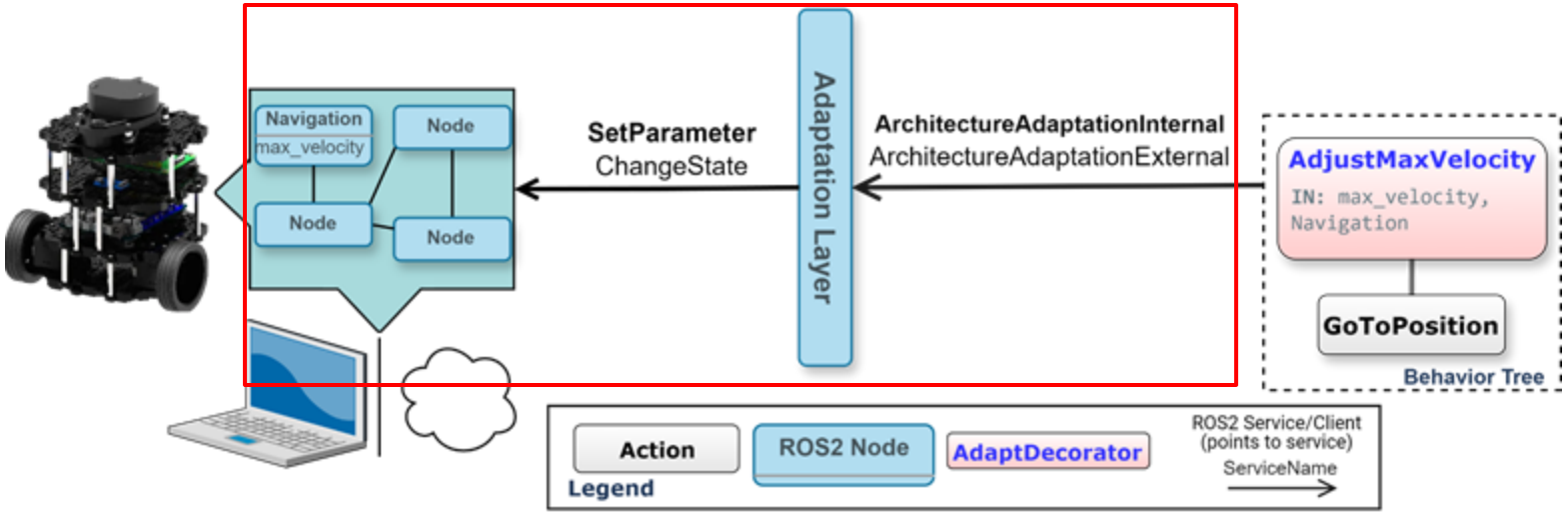

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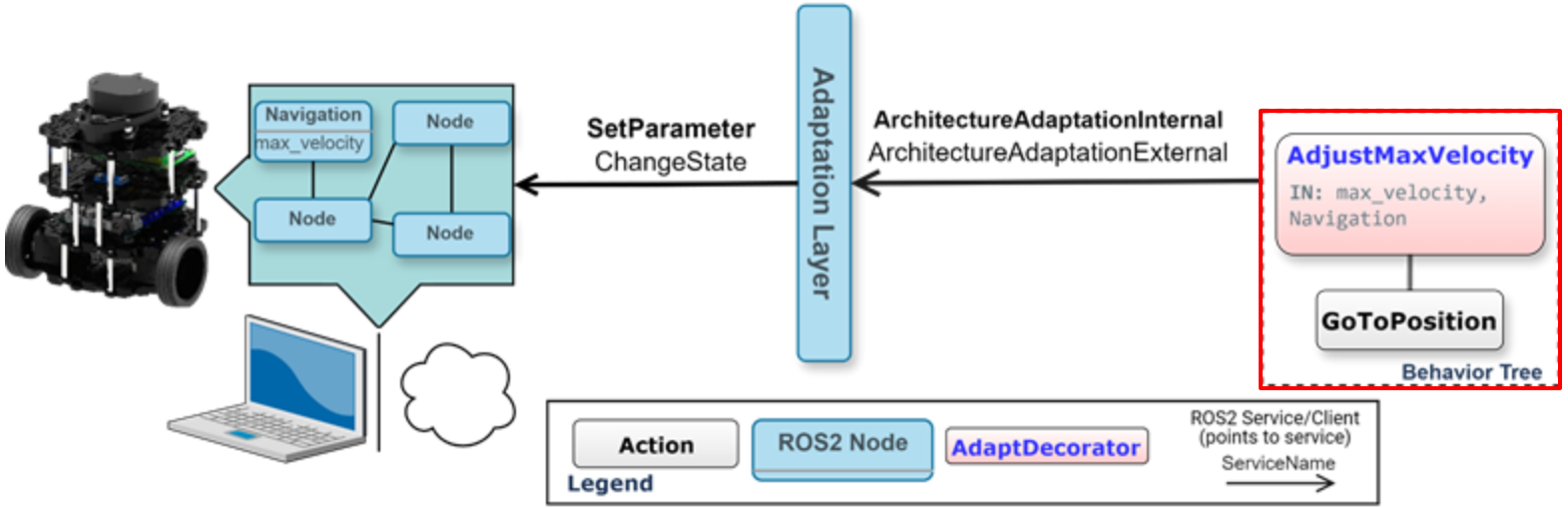
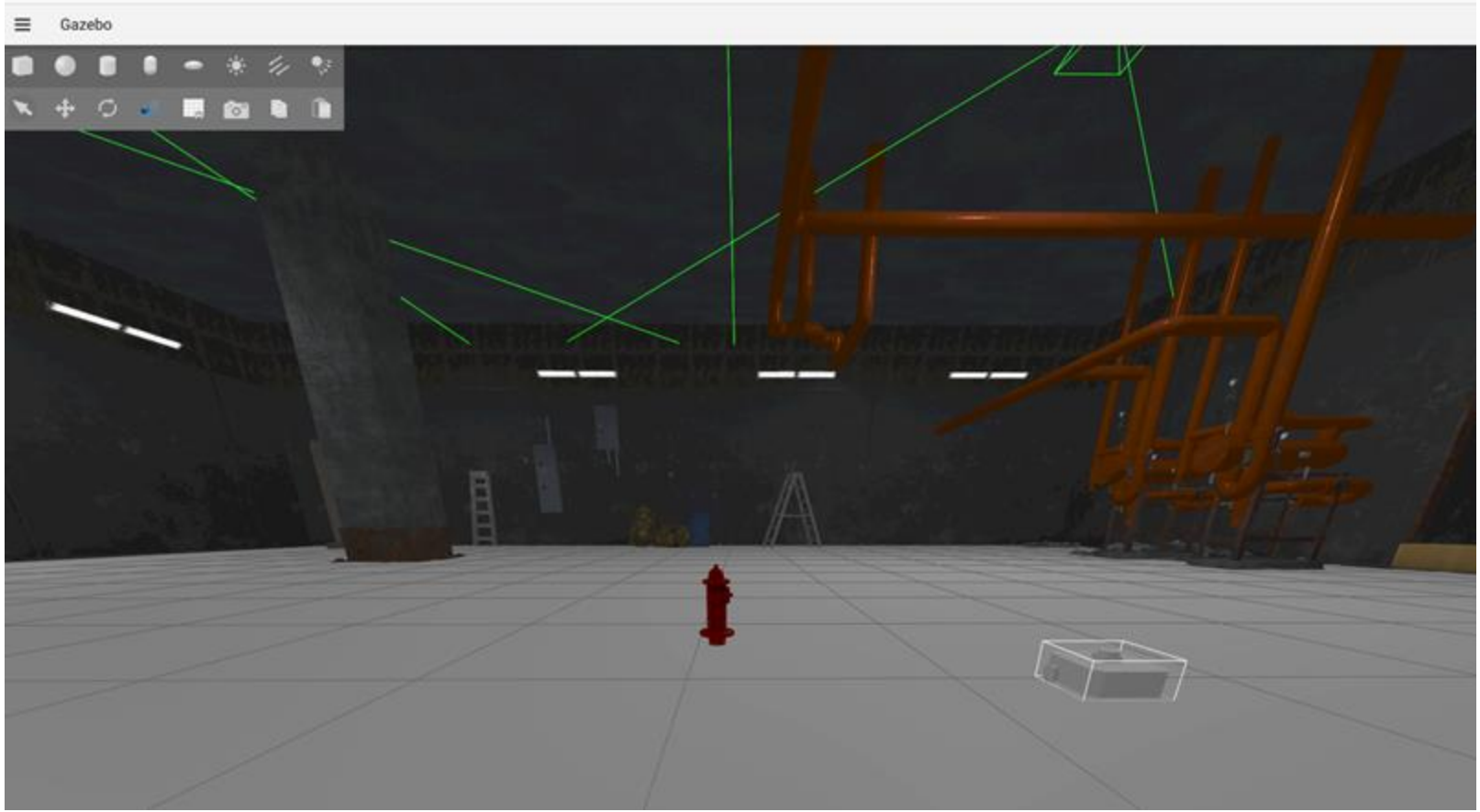
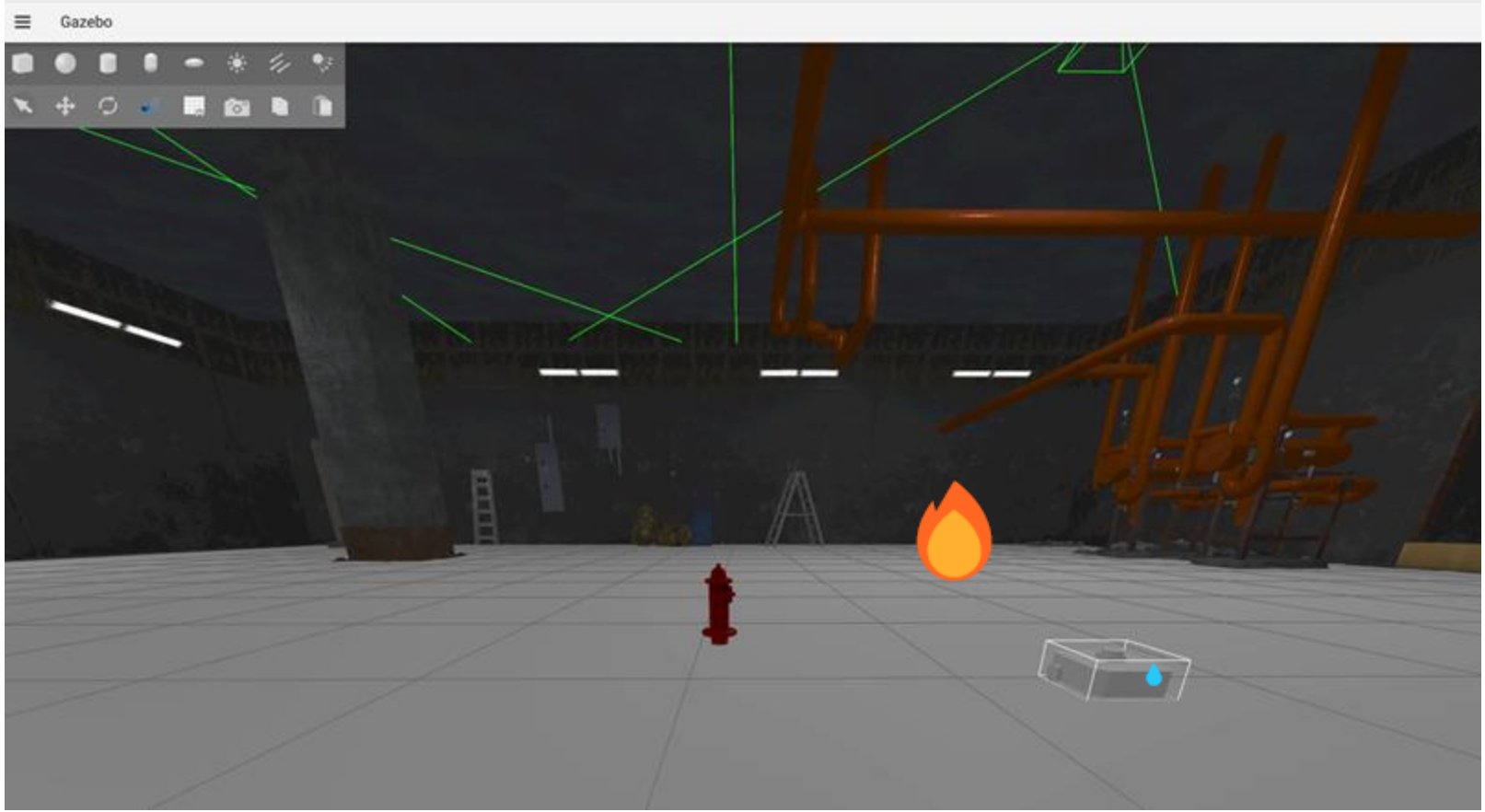


Let’s put it all together concretely.

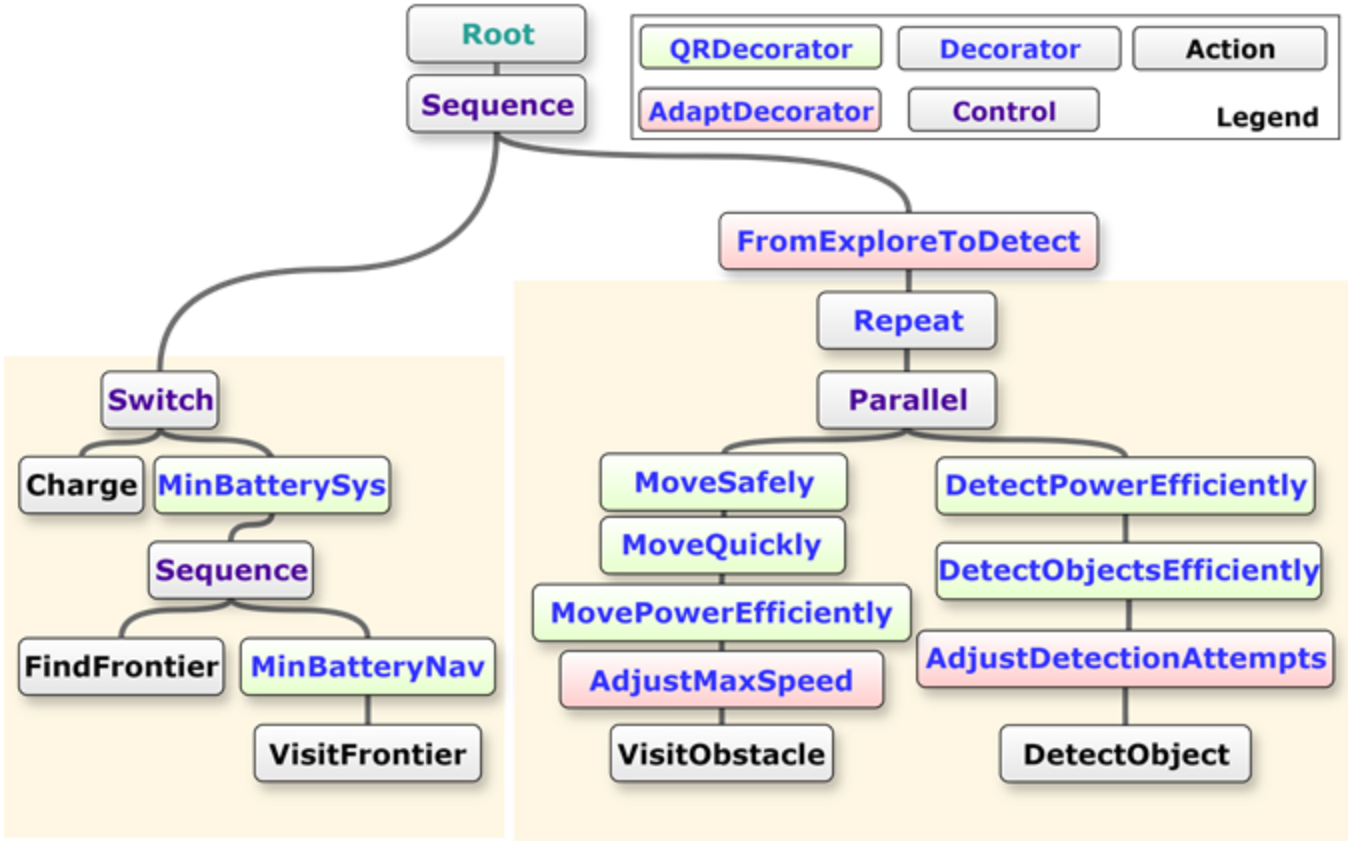
FROG



FROG and his newfound mission



A tree for our mission



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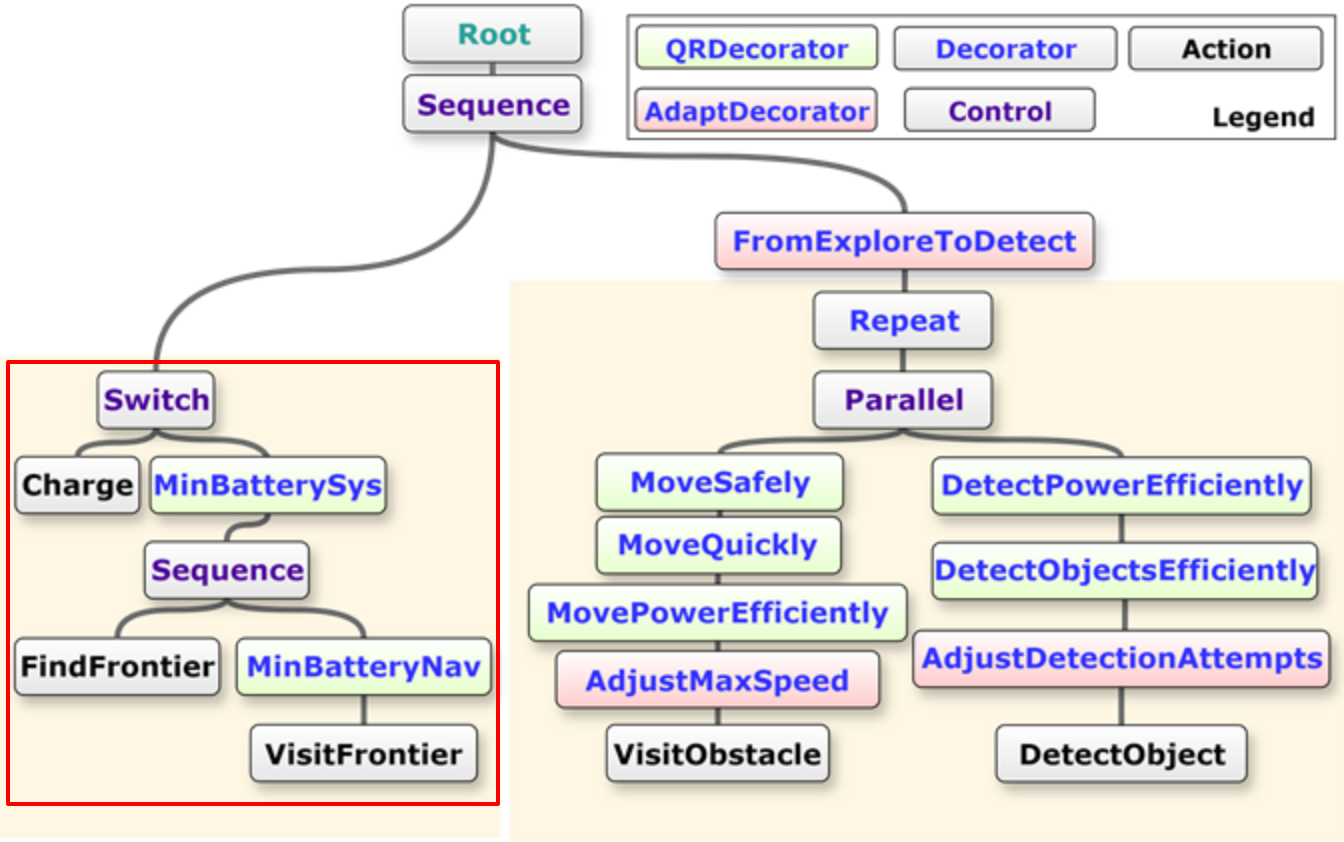

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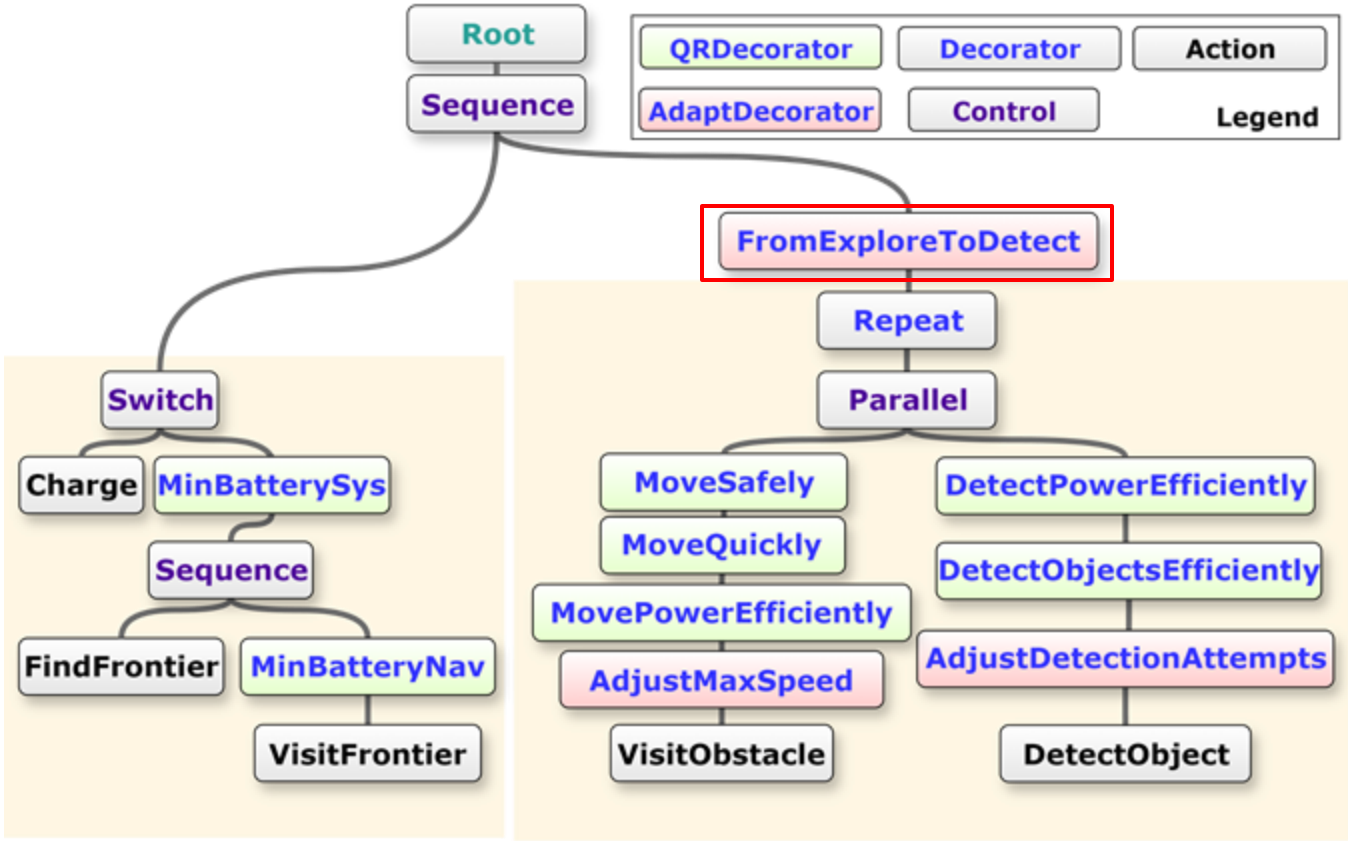

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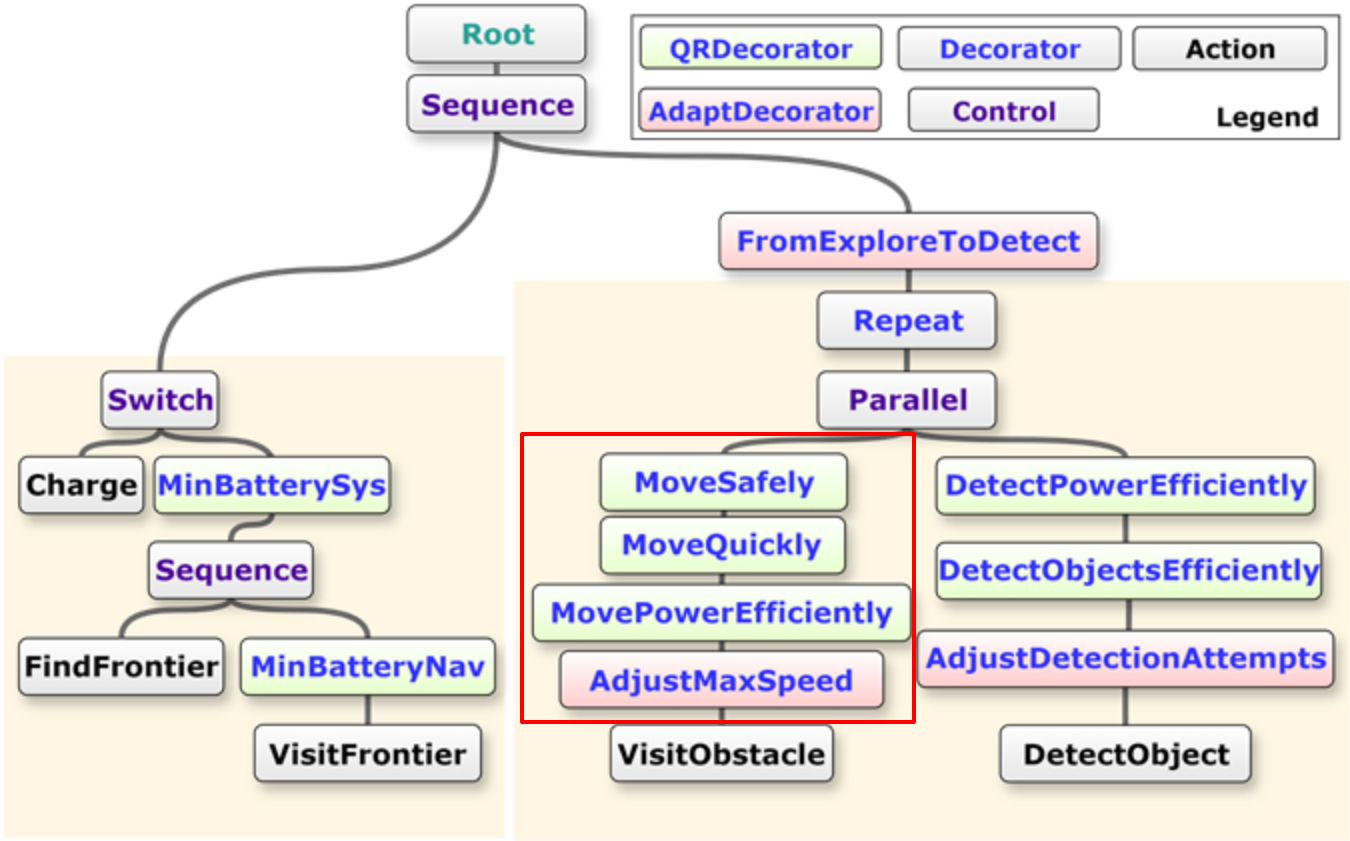
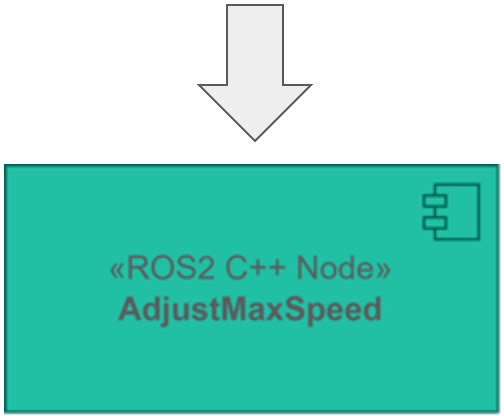


AdjustMaxSpeed

Behind the scenes

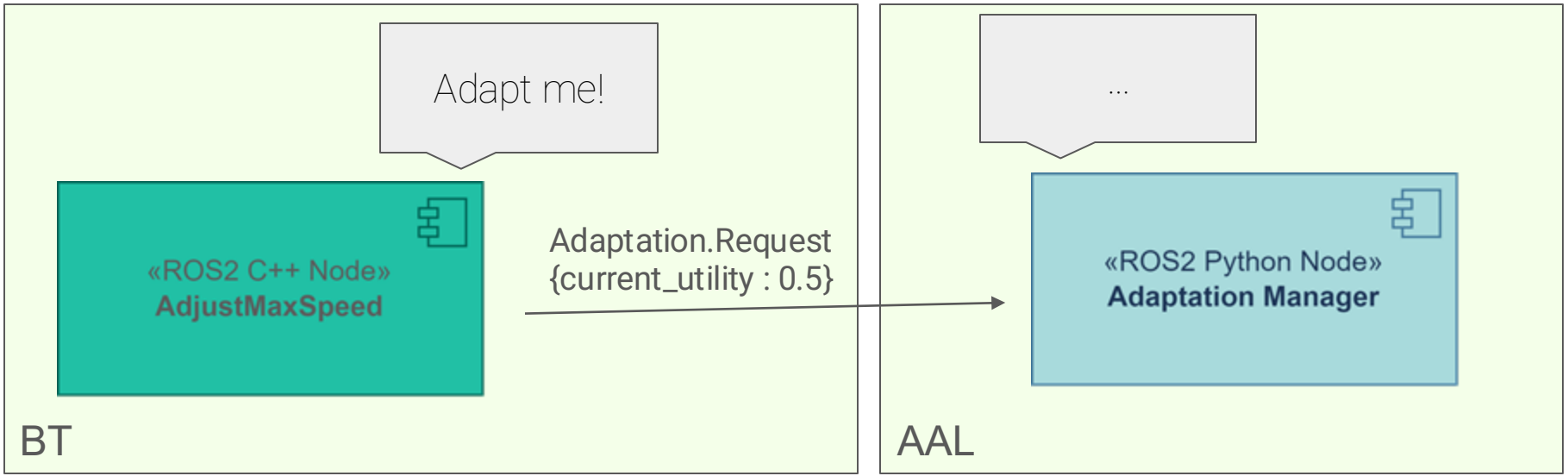
```
<AdjustMaxSpeed
adaptation_strategy="ucb_strategy" adaptation_options="0.10;0.18;0.26"
adaptation_subject="max_velocity" subject_location="velocity_smoother">
```

XML



AdjustMaxSpeed

Behind the scenes



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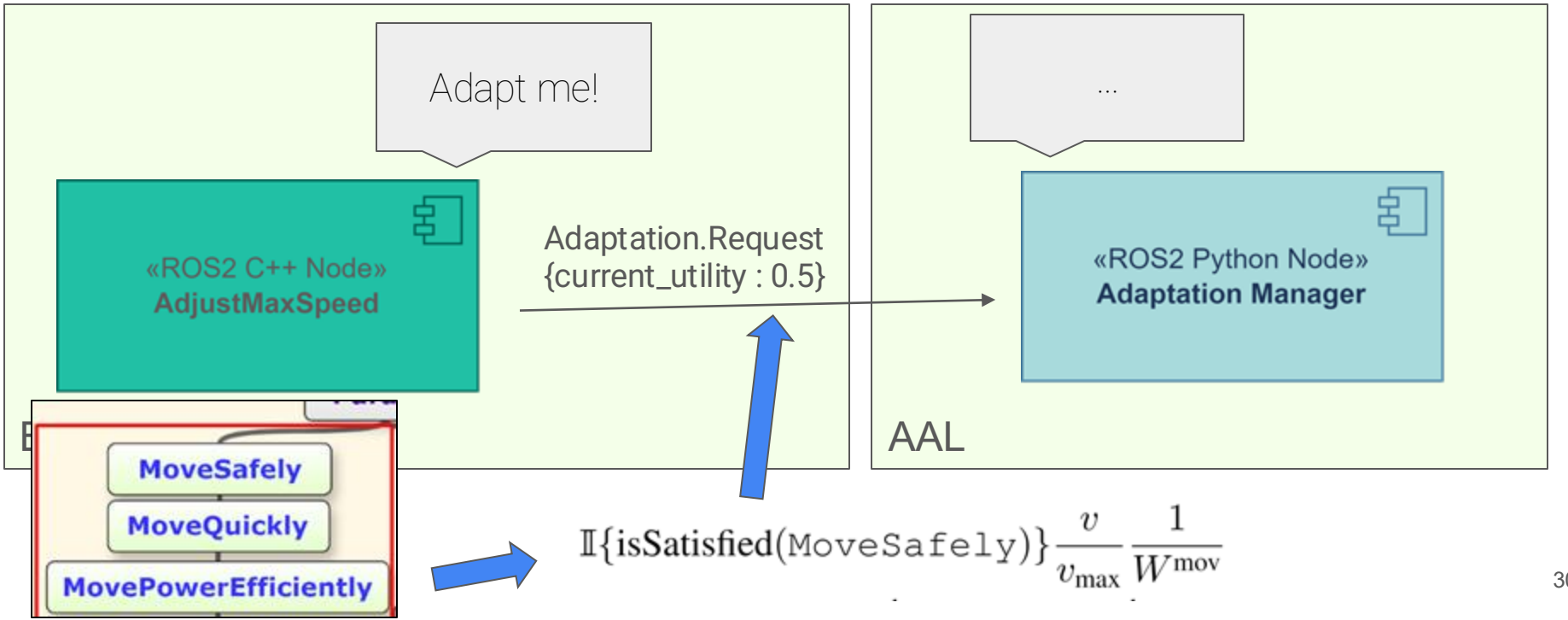
Behind the scenes



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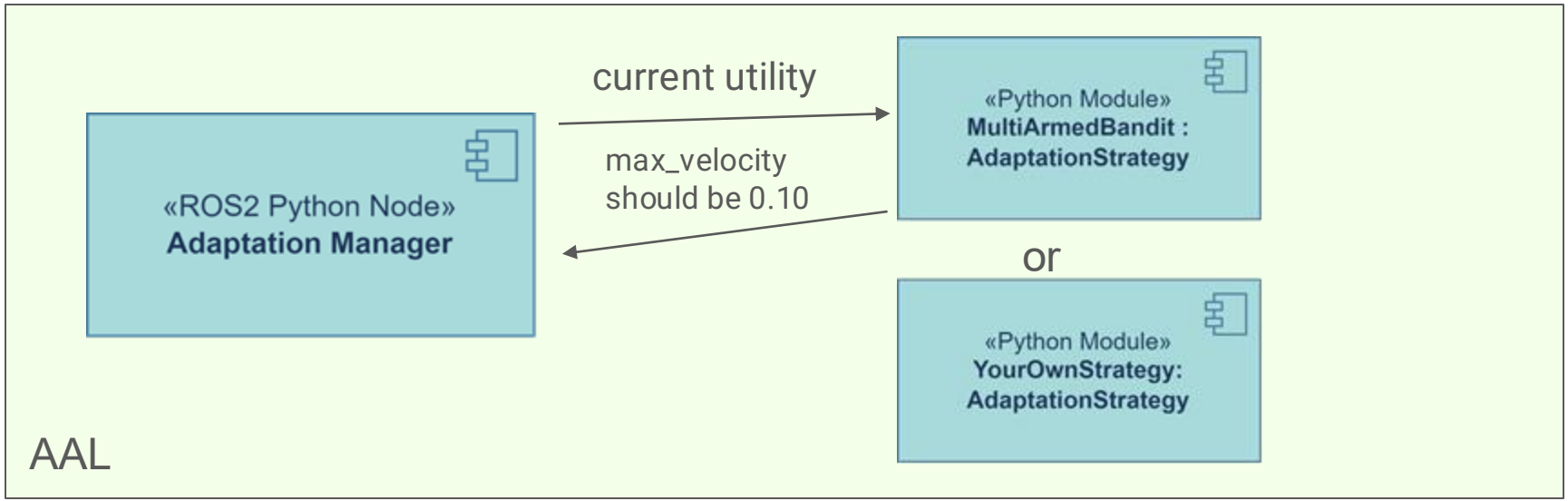
Behind the scenes

Two ROS2 Nodes walk into a bar…



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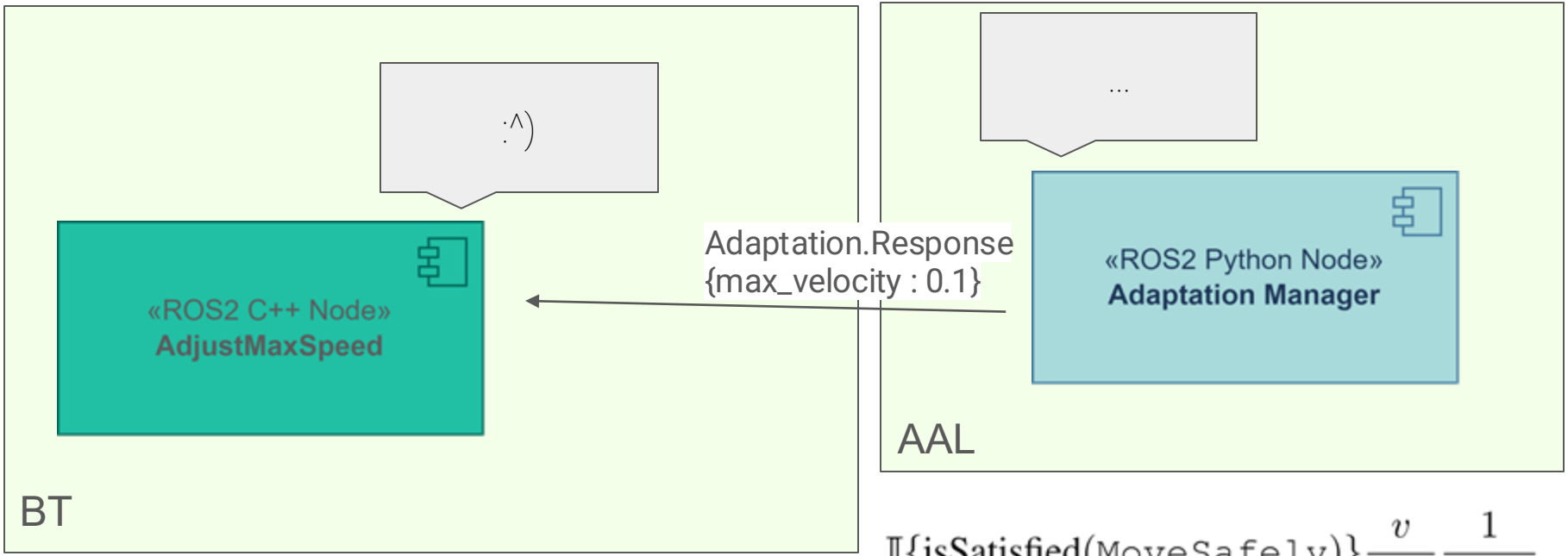
Behind the scenes

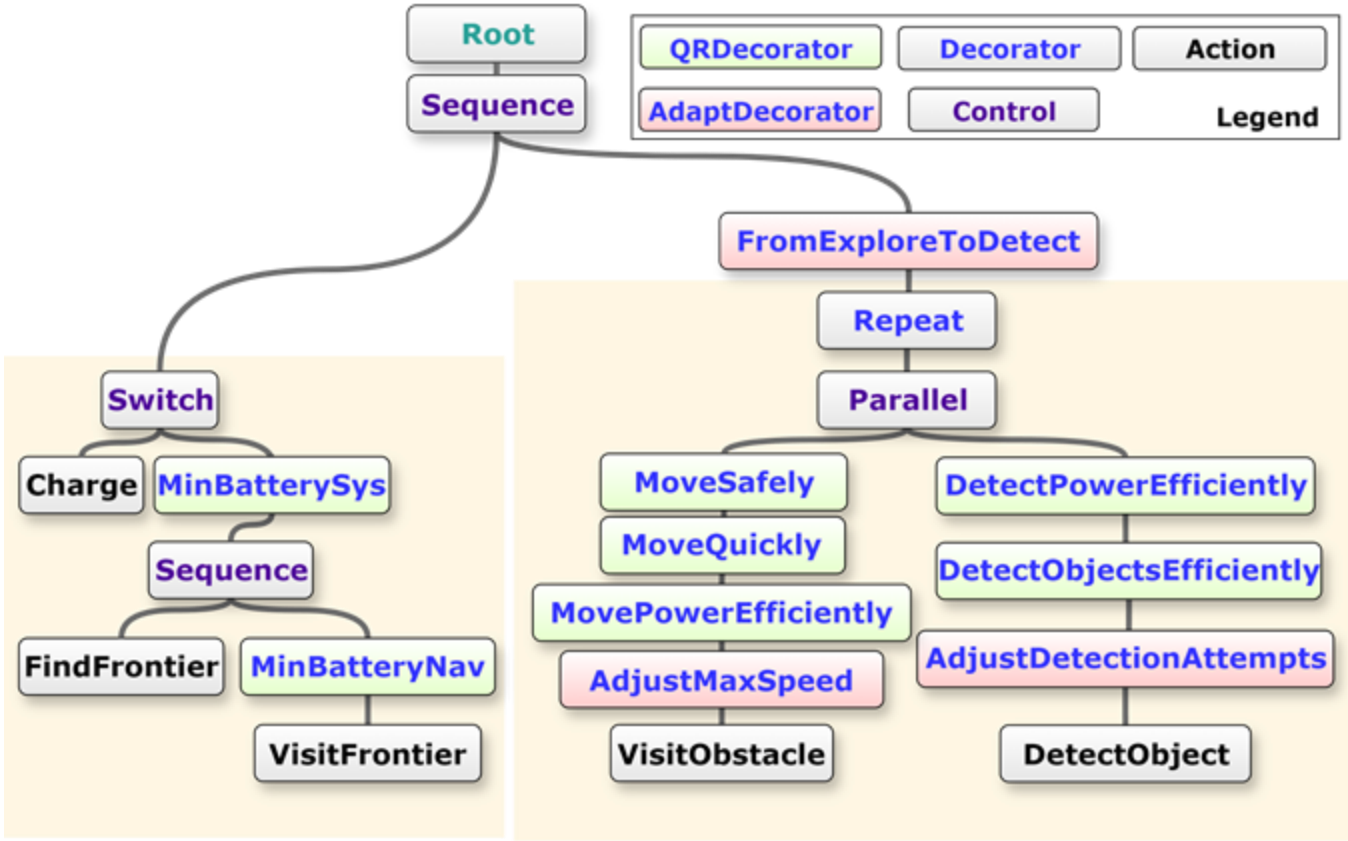
Two ROS2 Nodes walk into a bar...



$$\mathbb{I}\{\text{isSatisfied}(\texttt{MoveSafely})\}\frac{v}{v_{\max}}\frac{1}{W^{\text{mov}}}$$

Hopefully things can often be simpler.

A tree for our mission



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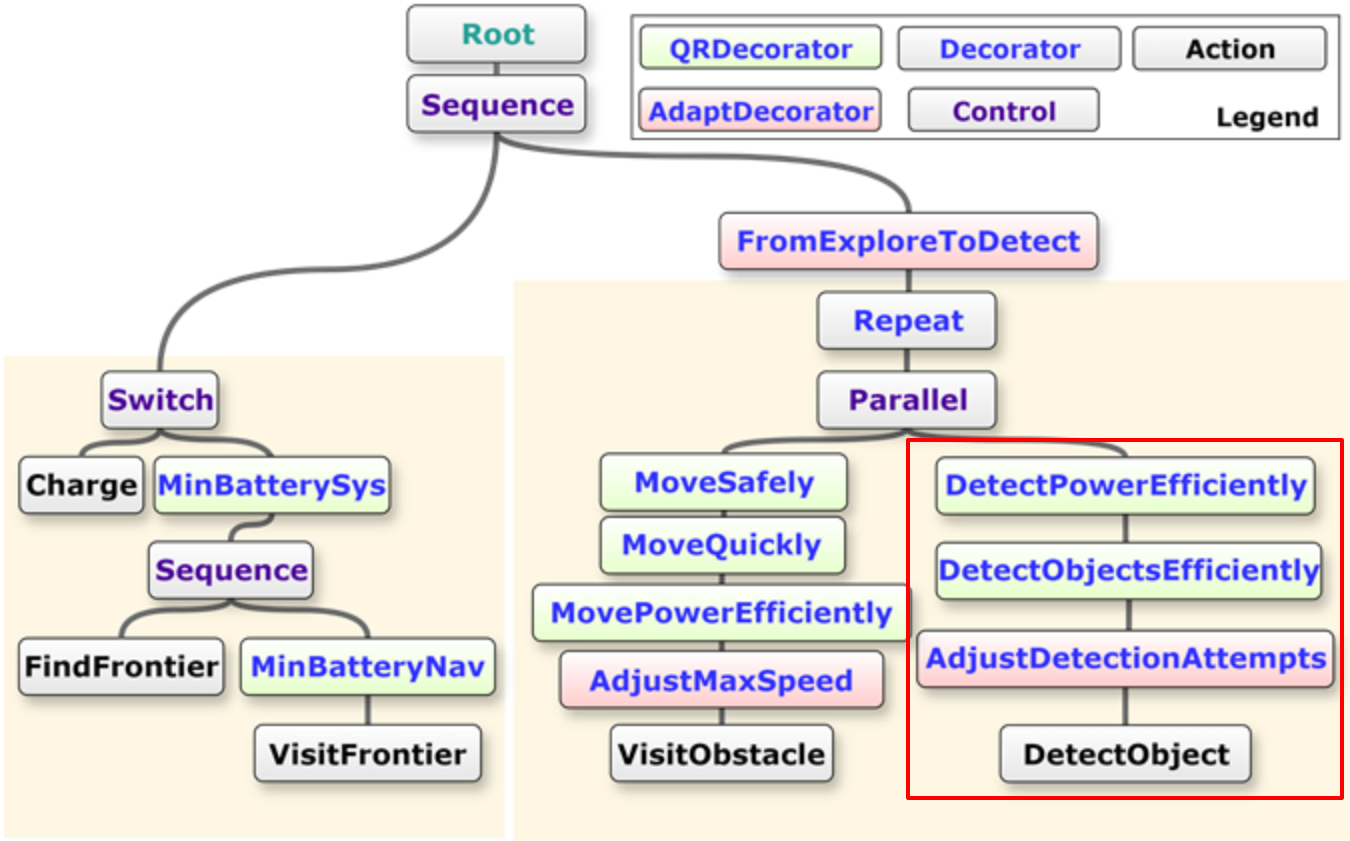

Behind the scenes

```
virtual bool evaluate_condition() override
{
    if(remaining_power_budget < 0.0) {
      return change_camera_feed(ALTERNATE_CAMERA);
    }
    if((current_darkness) > 0.70) {
        if(remaining_power_budget >= power_to_be_used &&
remaining_power_budget > 0.0) {
          return increase_picture_rate() || change_camera_feed(ROBOT_CAMERA);
        }
        else {
          return change_camera_feed(ALT_CAMERA_TOPIC);
        }
    }
    else {
      return (reduce_picture_rate() || change_camera_feed(ROBOT_CAMERA));
    }
}
```

Behind the scenes

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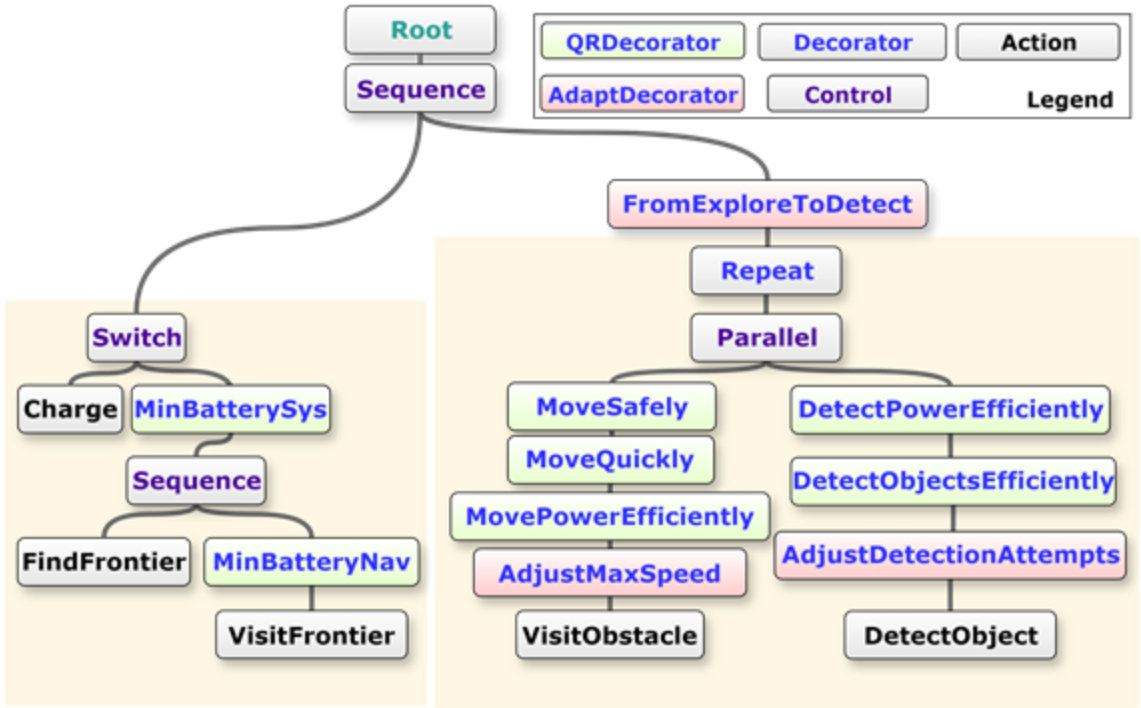
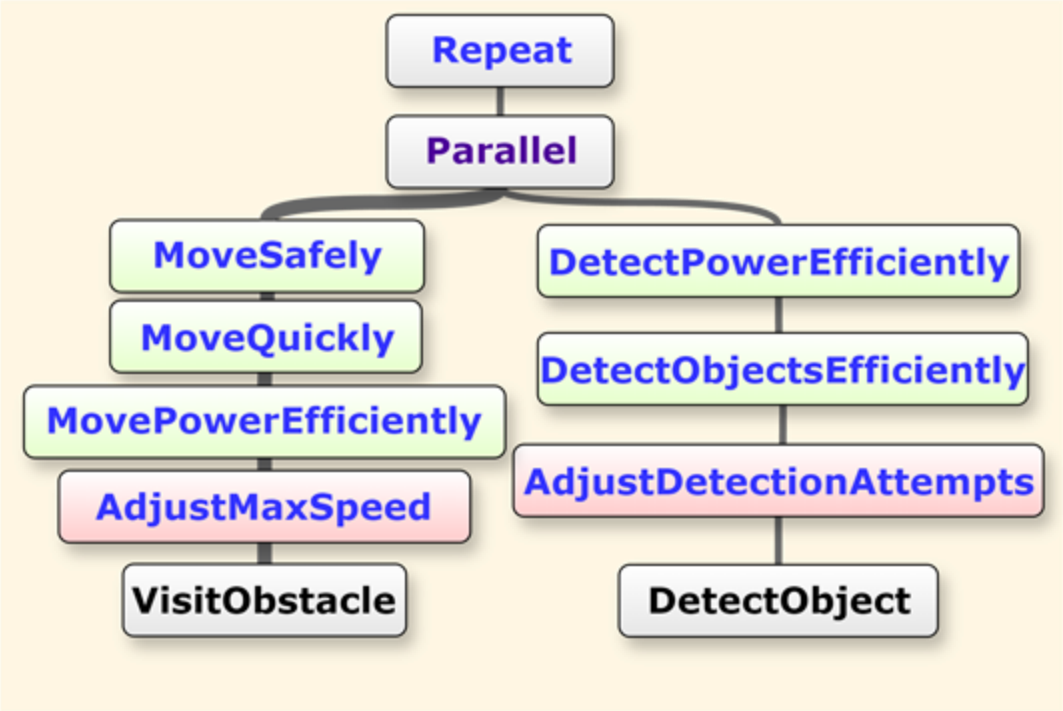
```

Something Interesting, and Future Work



There is no tree.

Something Interesting, and Future Work



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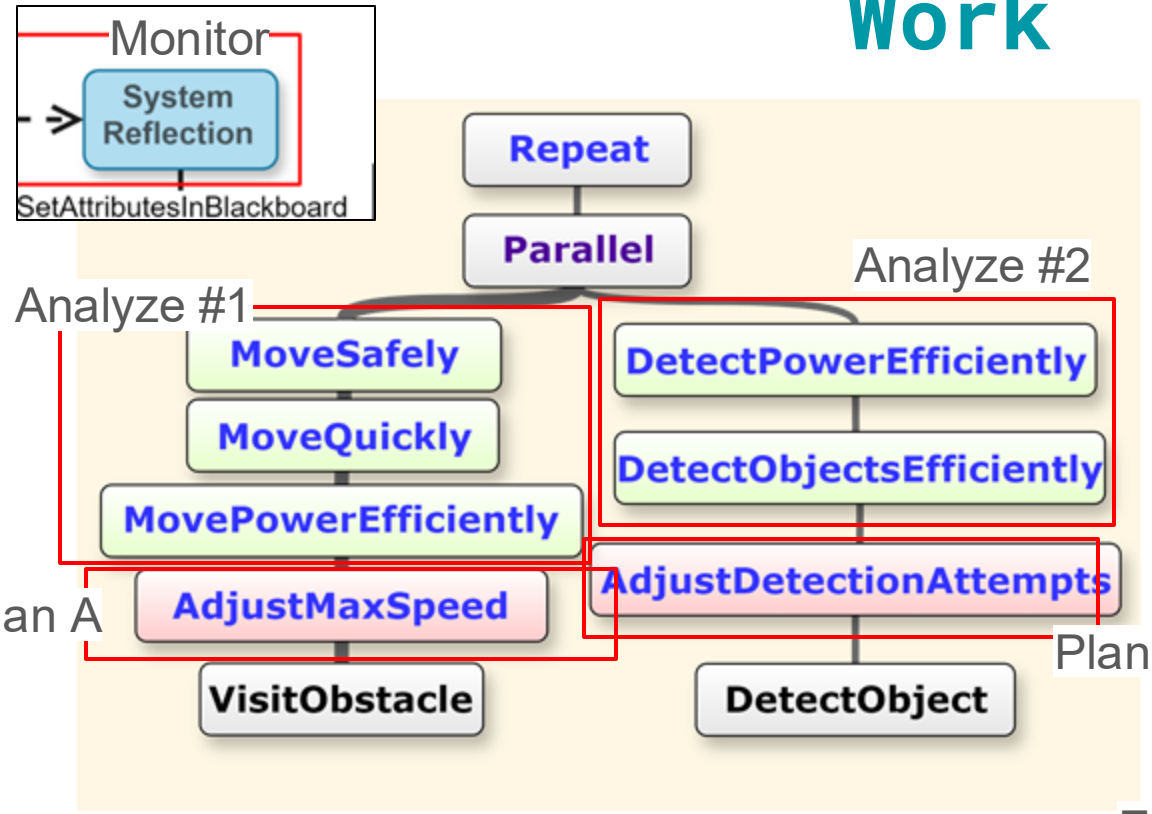

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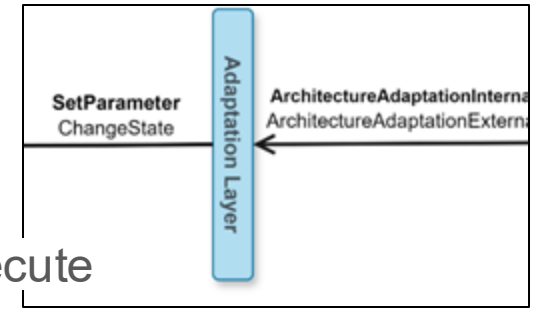
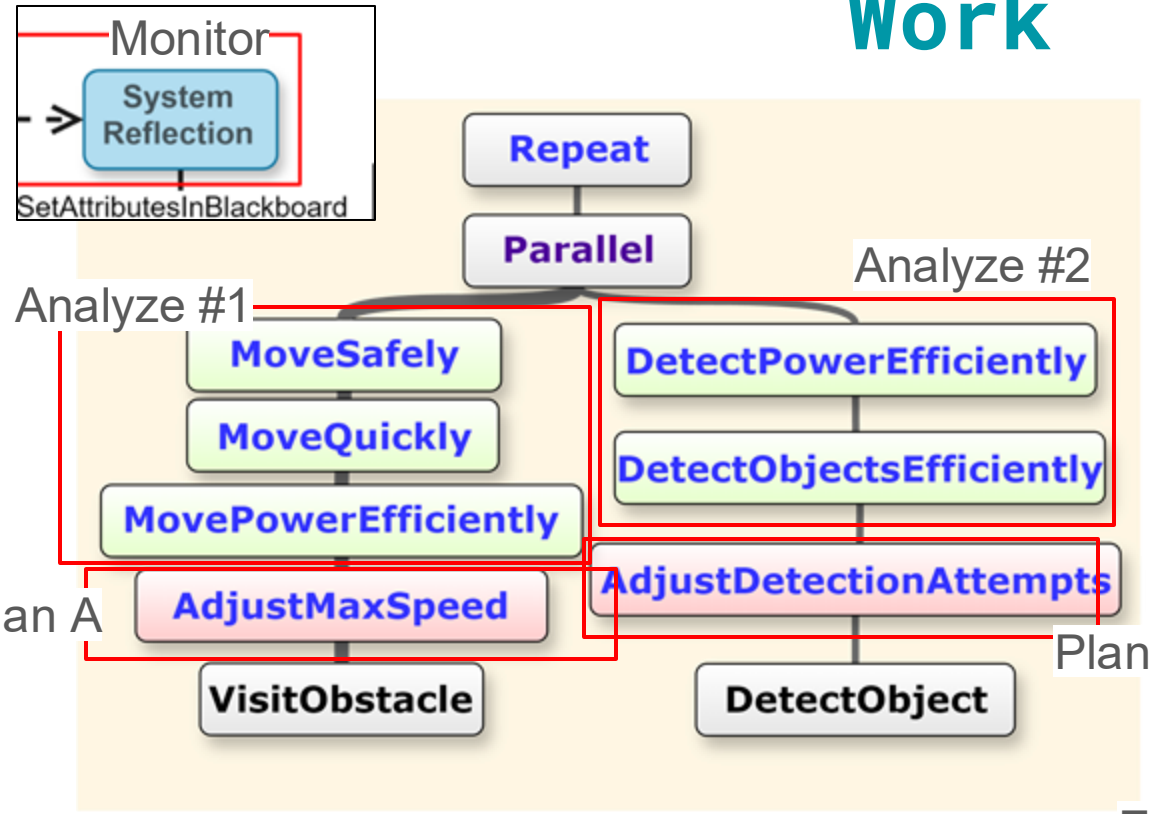
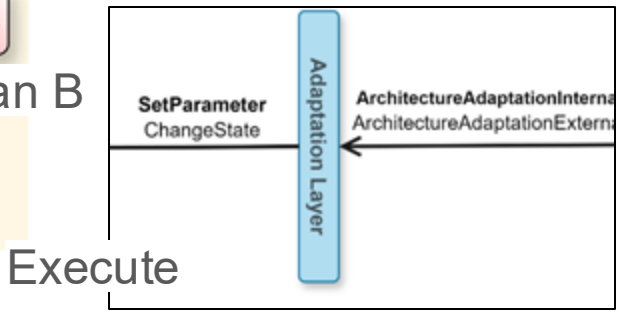


Something Interesting, and Future Work



Each branch of the tree entails its own realization of a MAPE-K loop. The management of these separate loops can be expressed through the logic already provided by BTs.



Something Interesting, and Future Work

- Our implementation of QR metrics is quite rudimentary.
- More types of architectural adaptation are still to be implemented for ROS2 e.g. redeployment of components.

We have an artifact