

ROSCon 2024: Manipulating with MoveIt Like a Pro

Ask questions via Slido: [slido.com #4109254](https://slido.com/#4109254)



If you haven't already done the getting started steps:

- Install Docker: <https://docs.docker.com/engine/install/ubuntu/>
 - Follow Docker post-install instructions:
<https://docs.docker.com/engine/install/linux-postinstall/#manage-docker-as-a-non-root-user>
- Exercise 1 setup:
 - Download `docker-image.tar.gz` from the repository releases
 - Clone the repository: `$ git clone https://github.com/moveit/roscon24.git`
 - `cd` into the `roscon24` repository
 - Get the image with the fetch script: `$ docker/fetch ~/Downloads/docker-image.tar.gz`
- Exercise 2 setup:
 - Follow the install instructions on [Quick Start | MoveIt Pro](#)
 - You should have received an individual **license key** for this workshop via email
- If you run into technical difficulties, let us know and we will try our best to fix them
- If you don't have a working installation, please group up with someone who does

Manipulating with MoveIt Like a Pro

ROSCon 2024
October 21, 2024

Presenters & Contributors



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PickNik Robotics



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PickNik Robotics



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Senior Autonomy
Developer
OTTO Motors



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Principal Solutions
Architect
PickNik Robotics

Disclaimer

Opinions here are of our own, and are not representative of employer

Agenda

8:00 - 8:30	Introduction to MoveIt
8:30 - 9:30	Exercise 1: Motion Planning and Execution with Move Group
9:30 - 10:00	Manipulation is not just Motion Planning
10:00 - 10:30	☕ Q&A and Break ☕
10:30 - 11:50	Exercise 2: The MoveIt Pro Approach for Robotic Manipulation
11:50 - 12:00	Summary and Q&A

Introduction to Motion Planning & Movelt

Who are you?

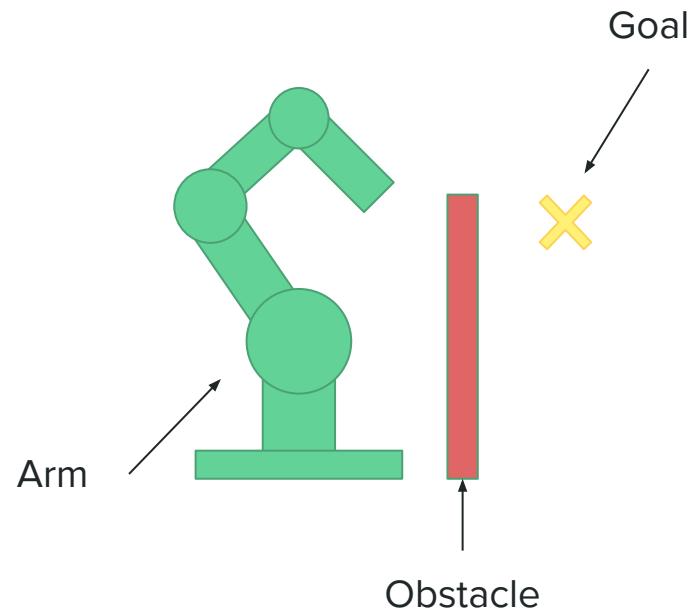
- Who works with robot arms on a daily basis?
- Who has used MoveIt 1?
- Who has used MoveIt 2?

Motion Planning (for Arms)

What is Motion Planning?

“Motion planning is the problem of finding a robot motion from a start state to a goal state that avoids obstacles in the environment and satisfies other constraints”

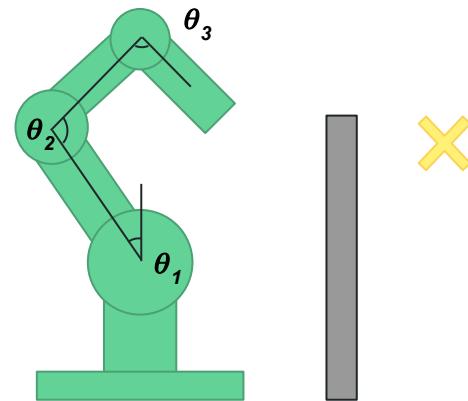
([Lynch, K. M., & Park, F. C. \(2017\)](#))



Paths & Trajectories

“Motion planning is the problem of finding a robot motion ...

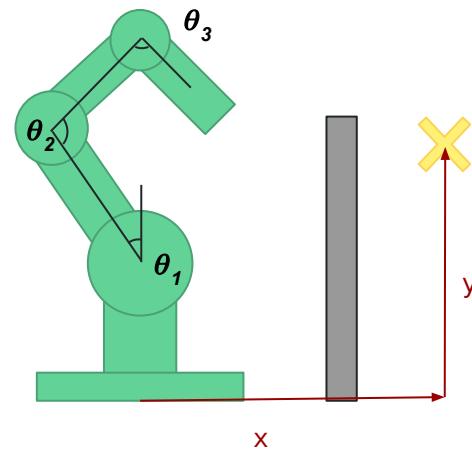
- We can control the joint angles of the robot arm to change its position
- To do a motion, we need to come up with a sequence of joint state setpoints (Robot states) this is called **path**
- But we also need to know, when which control is applied or define dynamic properties like joint velocities. A path with timing information is called **trajectory**



Tool & Joint Space

“Motion planning is the problem of finding a robot motion from a start state to a goal state ...

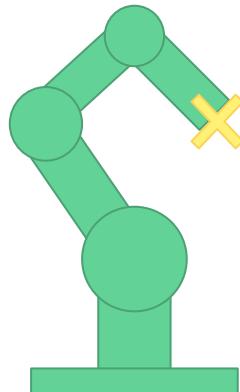
- Robot state is described by a set of joint angles ($\theta_1, \theta_2, \dots \theta_n$). Typical industrial arms have 6-7 joints.
- Goal state is often described by operators in Cartesian space (x, y, z, r, p, y)



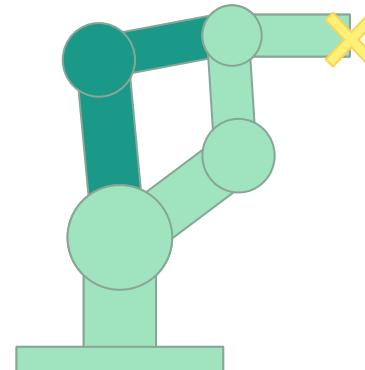
Kinematics

“Motion planning is the problem of finding a robot motion from a start state to a goal state ...

$(\theta_1, \theta_2, \dots \theta_n) \rightarrow (x, y, z, r, p, y)$ is
called Forward Kinematics

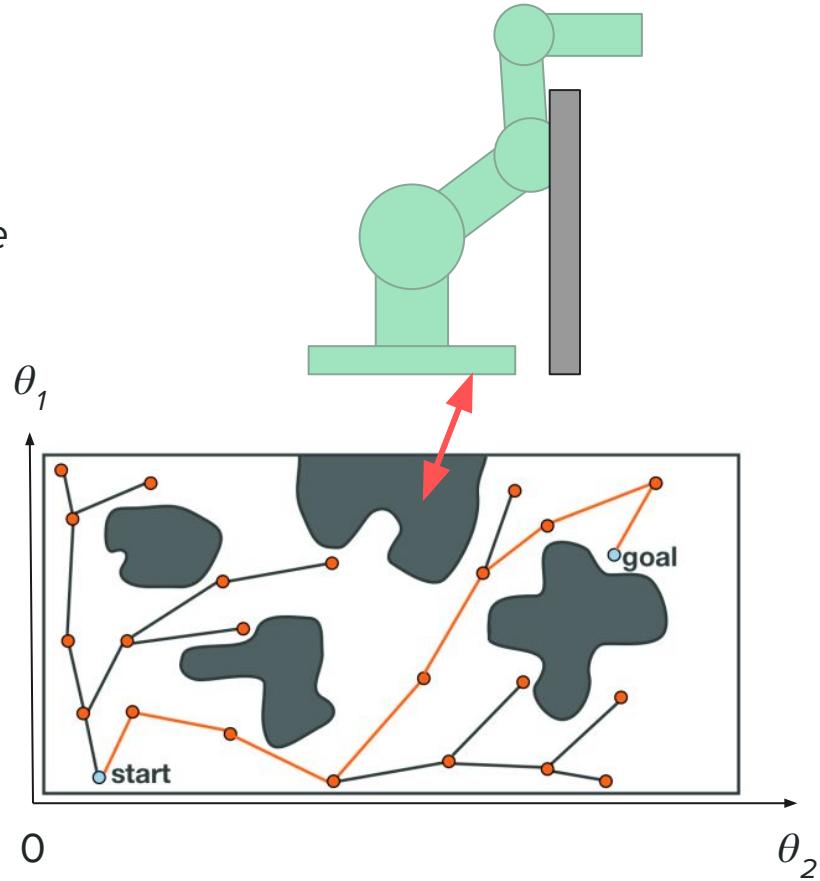
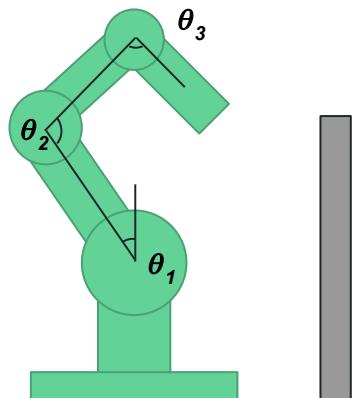


$(x, y, z, r, p, y) \rightarrow (\theta_1, \theta_2, \dots \theta_n)$ is
called Inverse Kinematics



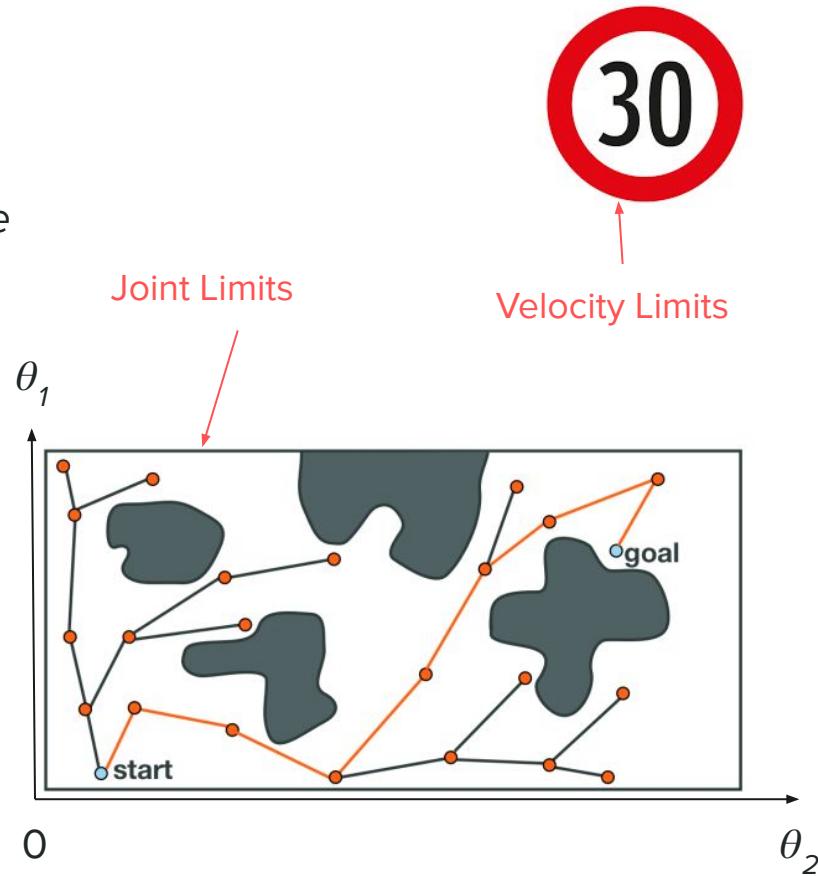
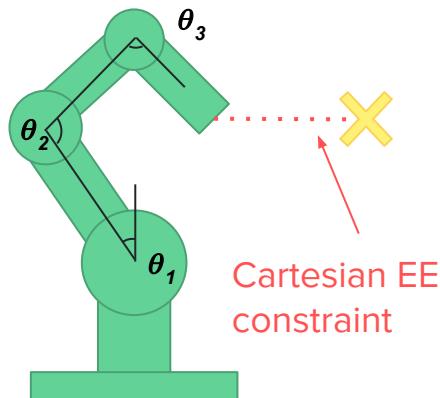
Collision Checking

“Motion planning is the problem of finding a robot motion from a start state to a goal state that avoids obstacles ...



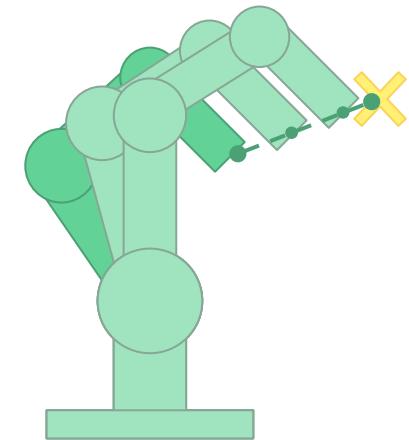
Constraints

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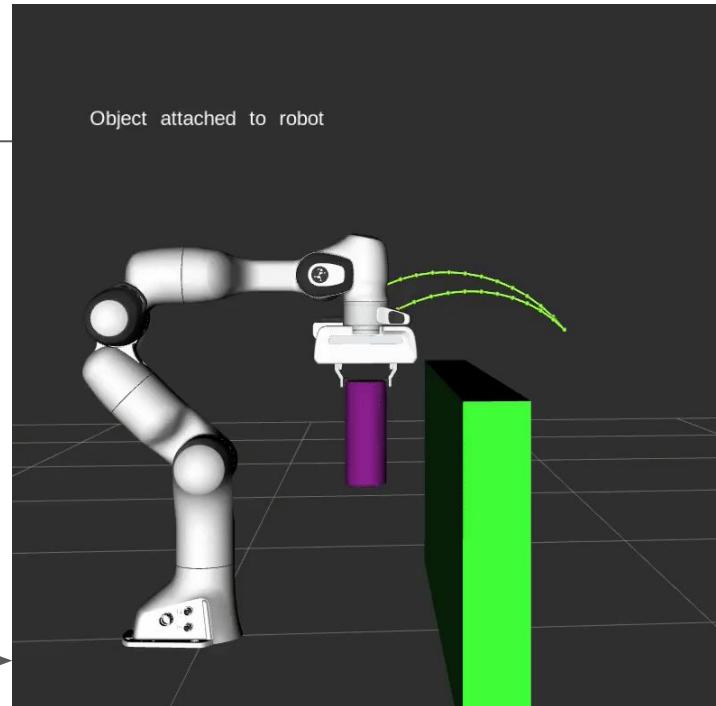
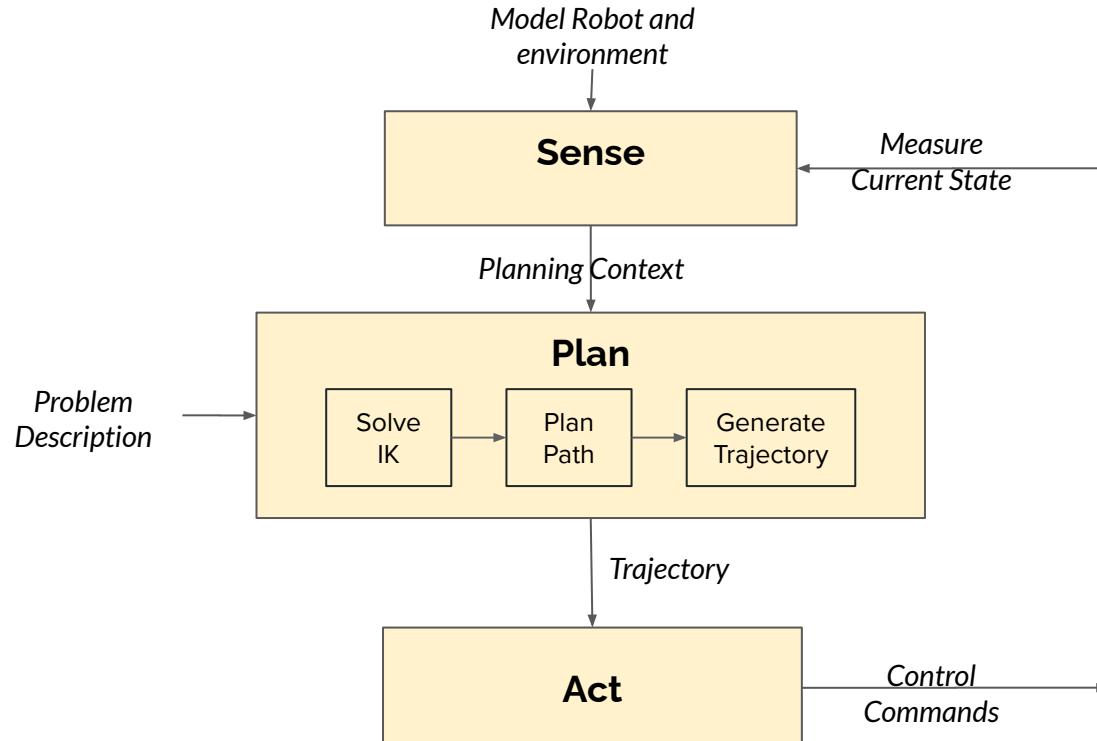


Planning in Tool Space

- Sometimes, you can have a desired end effector trajectory (toolpath, along a line)
 - Welding, cleaning, painting...
- Planning can be done in tool space (Cartesian) or joint space
 - Either try to translate the Cartesian constraint into Joint Space
 - Plan path along Cartesian trajectory, solving for joint states along the way (Requires a lot of IK to solve)



How can you solve a motion planning problem?

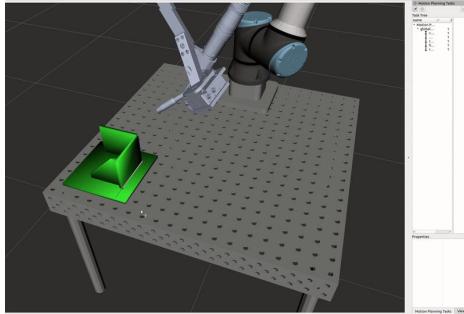


What is MoveIt?

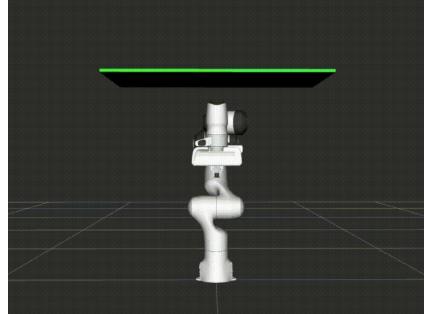
A ROS **motion planning framework** that integrates algorithms and approaches to plan and execute a robot motion



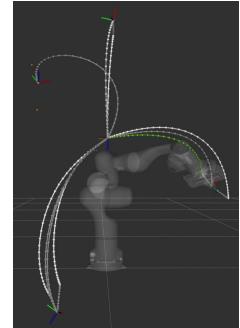
More MoveIt Features



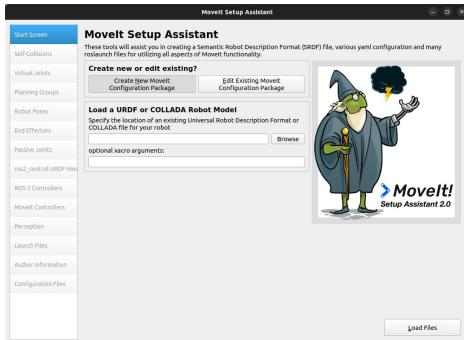
MoveIt Servo



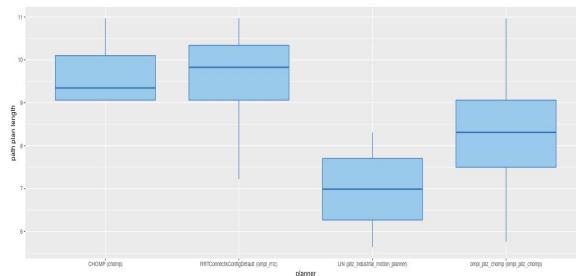
Hybrid Planning



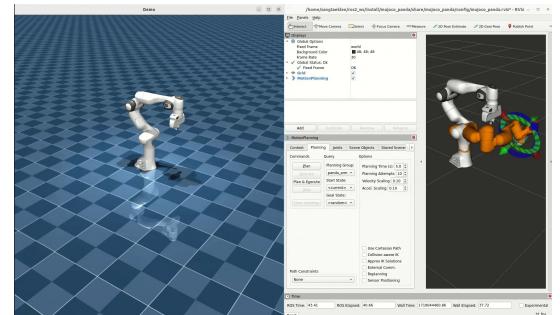
Trajectory Cache 



Setup Assistant

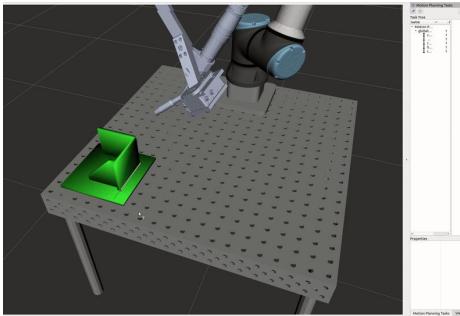


Benchmarking

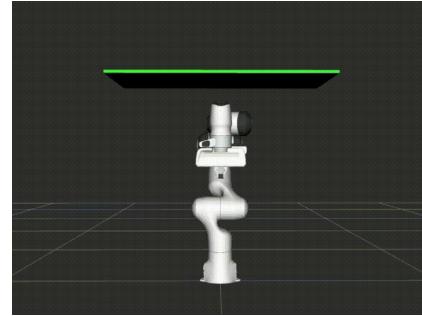


Simulation Integration

More Movelt Features



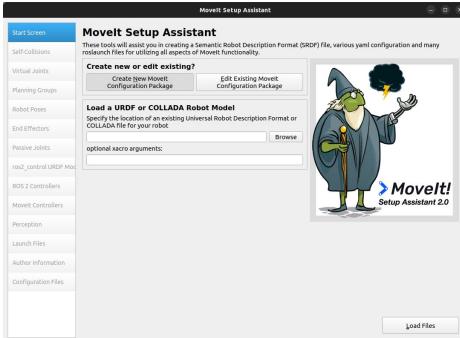
Movelt Servo



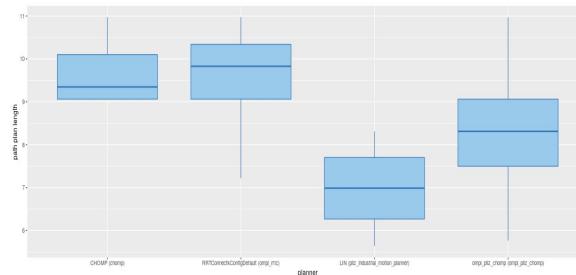
Hybrid Planning



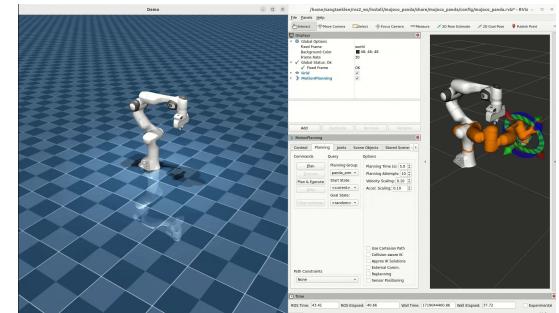
Trajectory Cache



Setup Assistant

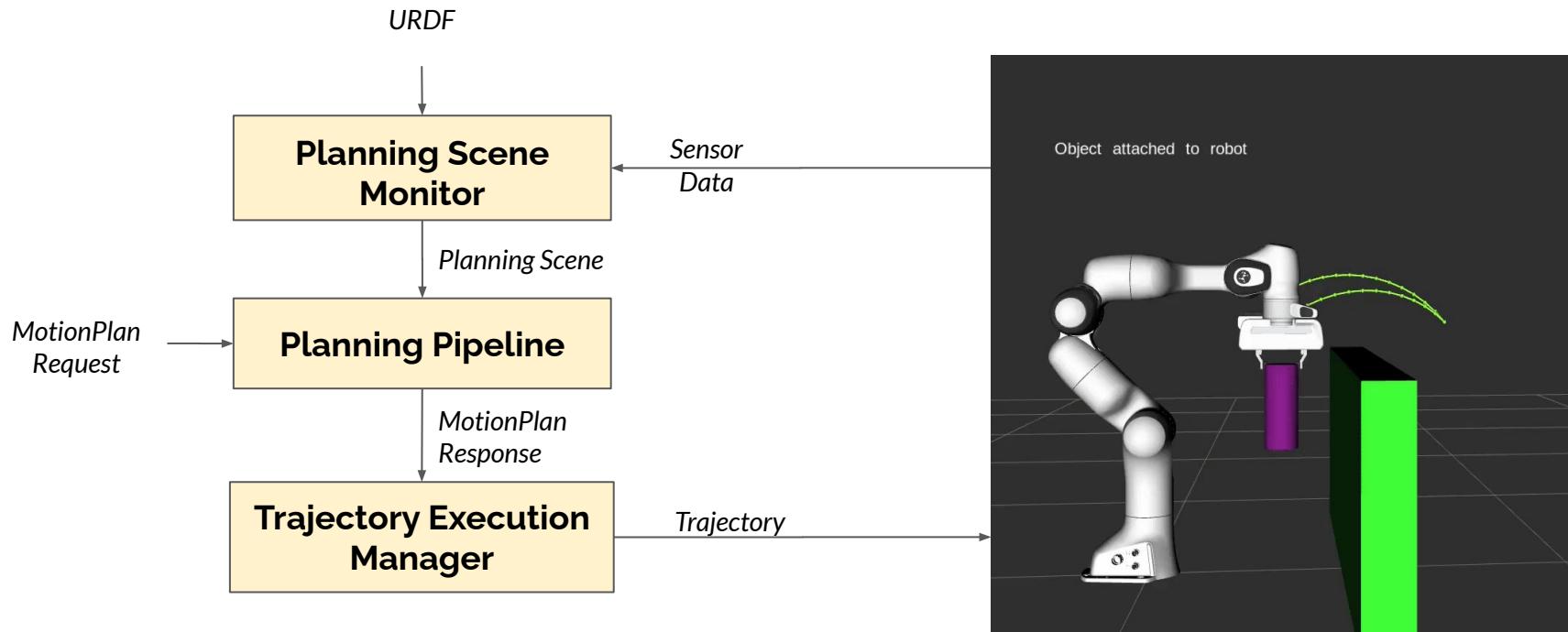


Benchmarking

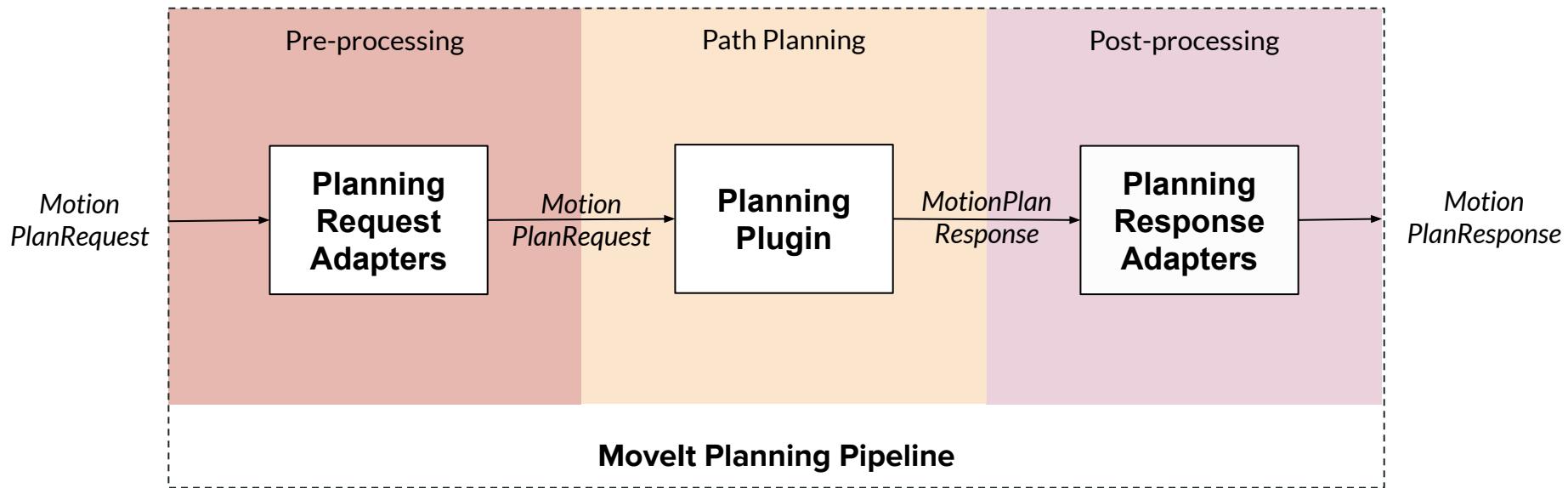


Simulation Integration

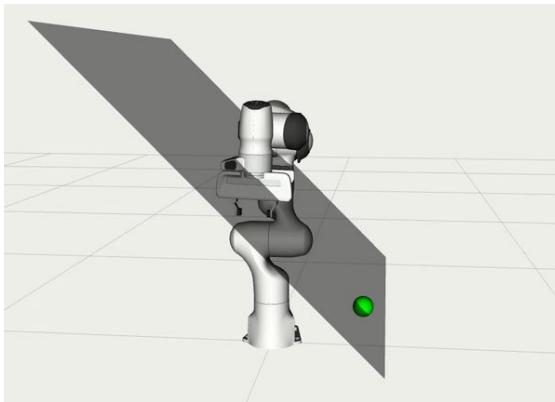
Terminology



The Planning Pipeline

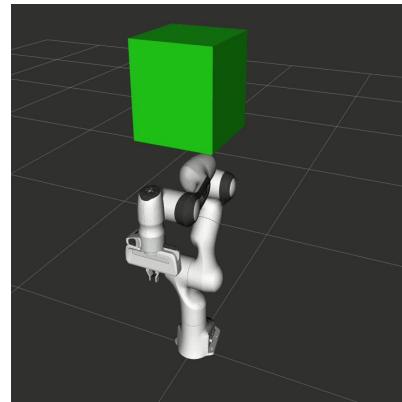


Main Planning Libraries



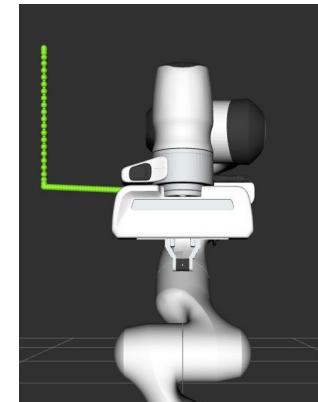
OMPL

- Library of sampling-based planners and frameworks
- Supports constrained planning



STOMP

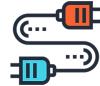
- **S**tochastic **T**rajectory **O**ptimization for **M**otion **P**lanning
- Optimizing planner



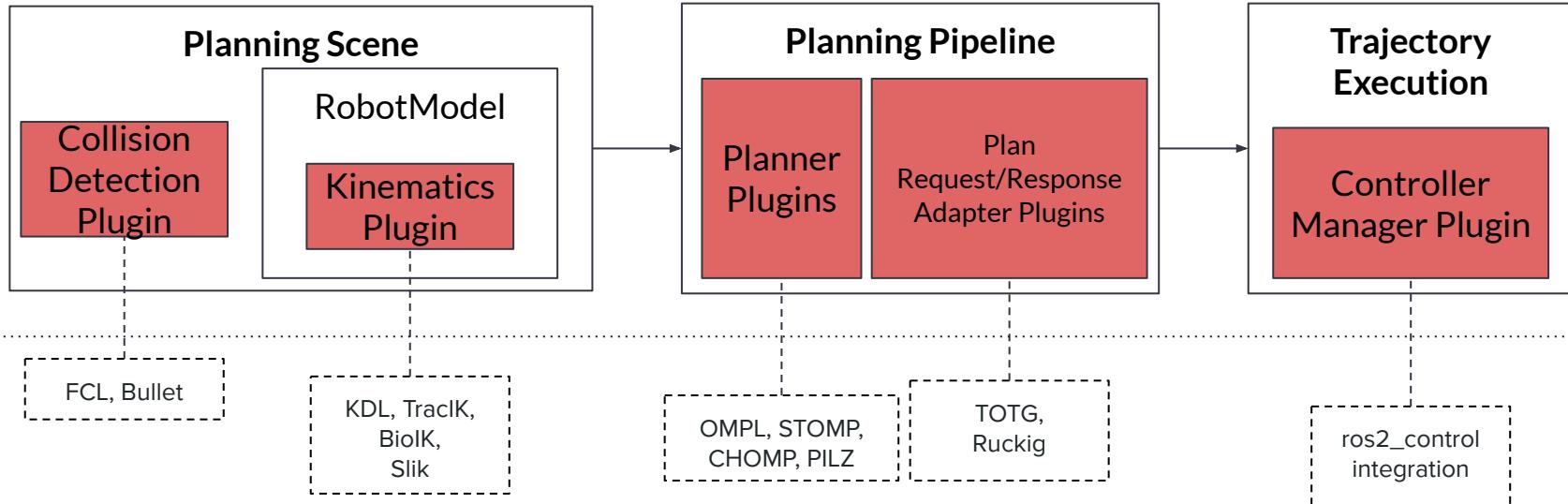
PILZ

- Industrial Motion Generator (LIN, PTP, CIRC)

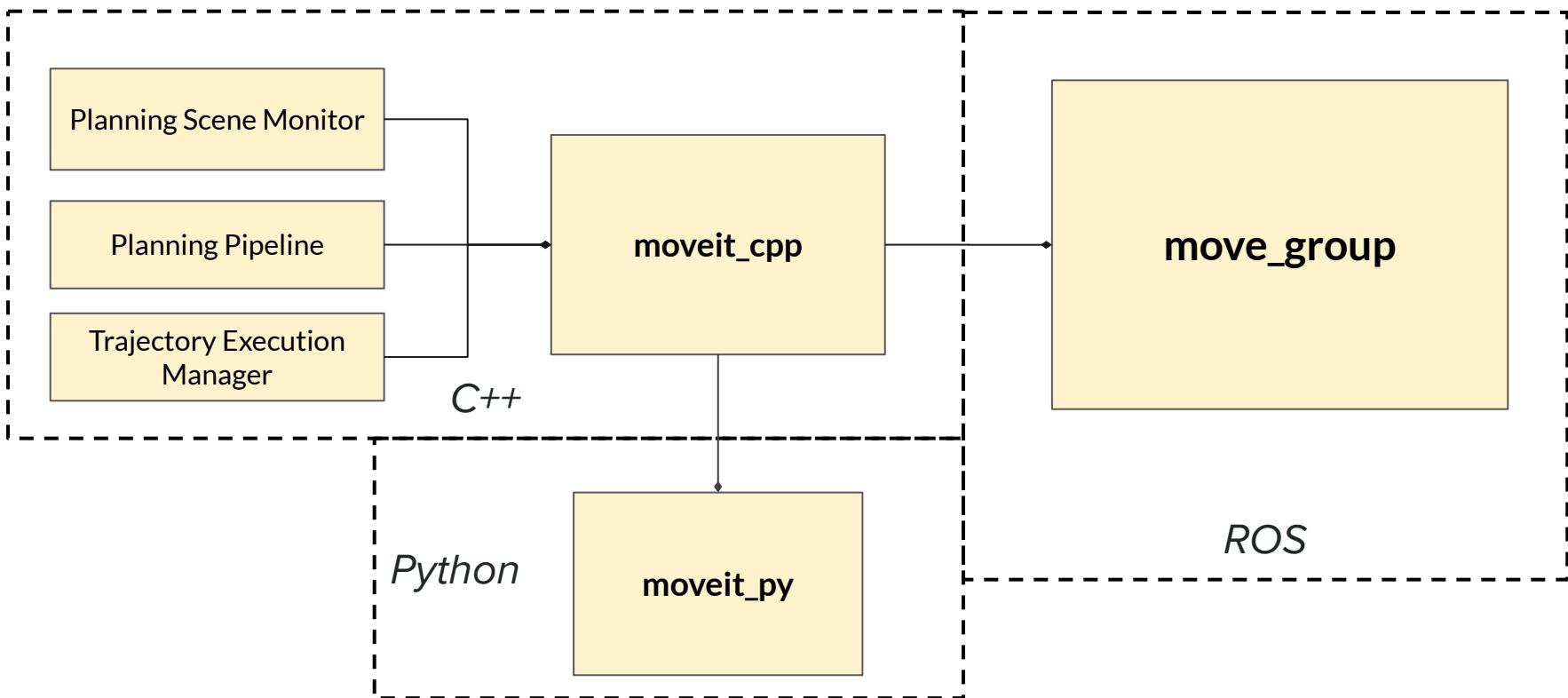
Plugins Plugins Plugins



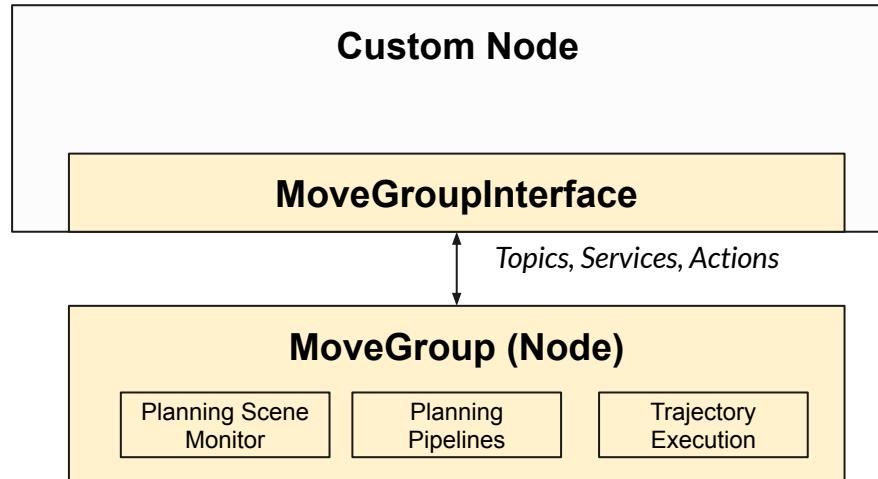
Movelit



Components and How use them



MoveGroupInterface



Exercise 1: Motion Planning and Execution with Move Group

Hot Dog Pick and Place

If you haven't already done the getting started steps:

- Download [docker-image.tar.gz](#) from the workshop repository latest releases
- Clone the repository:
 - `$ git clone`
<https://github.com/moveit/roscon24.git>
- `cd` into the `roscon24` repository
- Use the fetch script to get the image:
 - `$ docker/fetch`
`~/Downloads/docker-image.tar.gz`

Hot Dog Pick and Place

- The `exercise1` directory is a workspace
- Inside the workspace are three packages:
 - `exercise1-1`
 - Move group planning exercise
 - `exercise1-2`
 - Cartesian planning with move group
 - `hot_dog`
 - Meshes used in both exercises
- Start with a warm-up to test your setup and make your first motion plan

If you haven't already done the getting started steps:

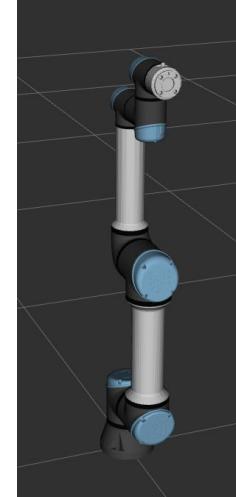
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Warm Up: Your First Motion Plan

- Exercises use a UR robot to assemble a hot dog
- Uses UR assets and driver from upstream UR packages
 - No gripper for simplicity
- Mock hardware
 - Measured joint states will exactly be the commanded joint states

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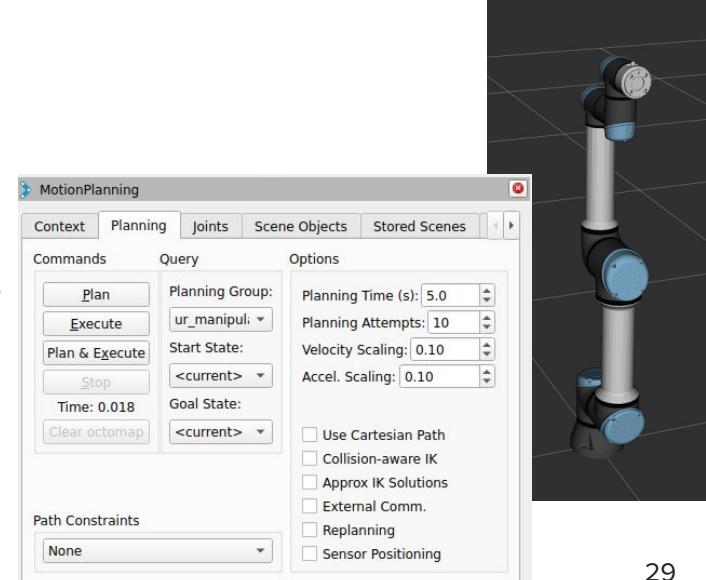


Warm Up: Your First Motion Plan

- Start and exec into the container:
 \$ docker/start
 \$ docker/shell
- Change directories to exercise1:
 \$ cd exercise1
- Build the workspace:
 \$ colcon build
- Source the workspace:
 \$ source install/setup.sh
- Start the UR mock with:
 \$ ros2 launch exercise1-1 ur.launch.py
 - Loads UR robot configuration and driver
 - Starts Move Group
 - Starts RViz
- Motion planning panel should be open on the left

If you haven't already done the getting started steps:

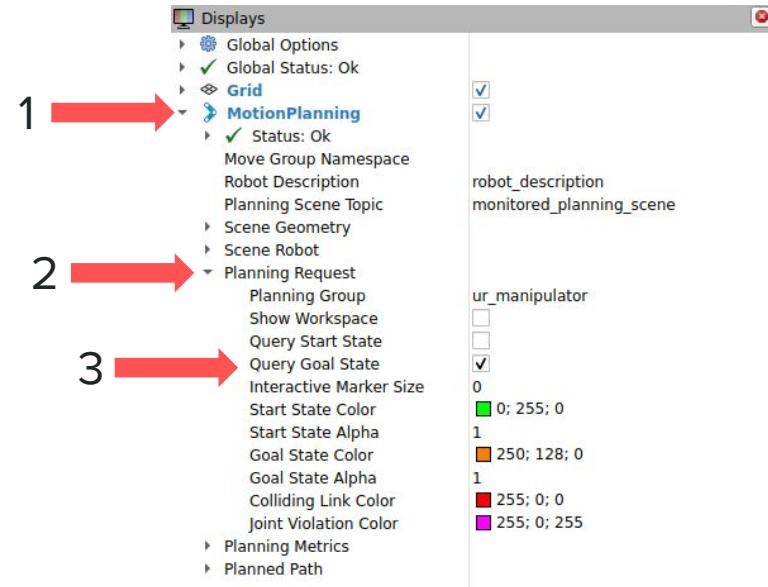
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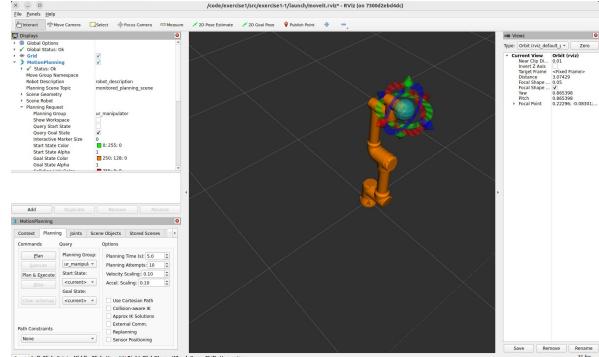
Warm Up: Your First Motion Plan

- Enable visualizing the goal state to start motion planning from RViz

1. Expand the “MotionPlanning” display
2. Expand “Planning Request”
3. Check “Query Goal State”

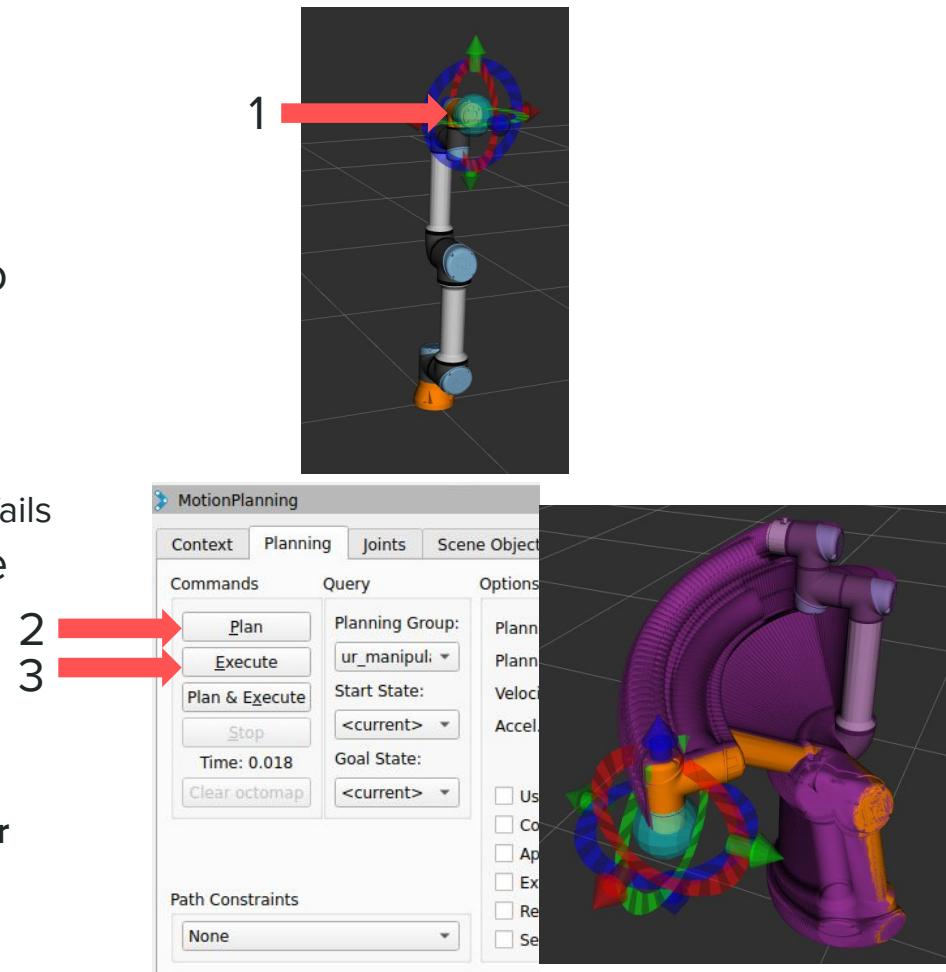


You should see an orange outline of the robot with an interactive marker (right)



Hot Dog Pick and Place

1. Drag the interactive marker around to set a goal state
2. Use the Plan button to plan to that goal state
 - o Retry a with a marker position if planning fails
3. Use the Execute button to move the robot according to the plan
4. Stop the UR mock (**Ctrl+C** in the terminal you ran it from)

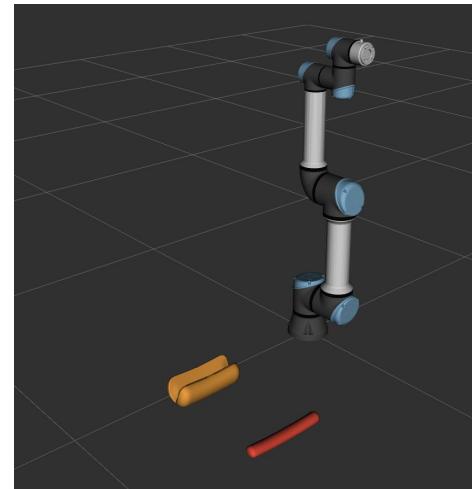


Note: Image on the right has Show Trails enabled for visualization purposes

Exercise 1-1: Hot Dog Pick and Place

Run Instructions

- Open a second terminal and run:
 - `$ docker/shell`
 - `$ cd exercise1`
 - `$ source install/setup.sh`
- **Terminal 1:** Restart the UR mock:
 - `$ ros2 launch exercise1-1 ur.launch.py`
- **Terminal 2:** Start exercise 1-1:
 - `$ ros2 launch exercise1-1 exercise1-1.launch.py`
- Should see the robot, a hot dog, and a bun (right)
- Stop all processes with **Ctrl+C**
- Let's make things move!

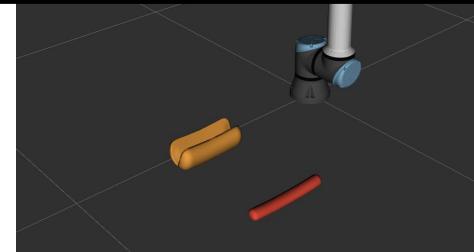


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Quick note:

- The workshop Docker container shares files in the repository between the host and container
- The next steps will involve looking at and editing source code
 - Please open the source files in an editor of your choice (on your host, **not** in the container)
- Saved changes to the source file from your editor will also be available in the container



Hot Dog Pick

File: exercise1/src/exercise1-1/src/main.cpp

```
25 // Create the MoveGroupInterface
26 using moveit::planning_interface::MoveGroupInterface;
27 const std::string planning_group{ "ur_manipulator" };
28 MoveGroupInterface move_group_interface(node, planning_group);  
  
29  
30 // Get predefined poses for pick and place above the sausage and bun respectively
31 const geometry_msgs::msg::Pose& pick_pose = hot_dog_scenario.getPickPose();
32 const geometry_msgs::msg::Pose& place_pose = hot_dog_scenario.getPlacePose();  
  
33  
34 // TODO(Exercise 1-1): Set the goal pose to the pick pose using MoveGroupInterface
35 // Add your code here  
  
36  
37 // Create a plan to that target pose
38 MoveGroupInterface::Plan pick_plan;
39 uint16_t pick_planning_attempts{ 0 };
40 bool pick_success{ false };
41 while (!pick_success && pick_planning_attempts < 5)
42 {
43     // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the pick pose and determine planning success
44     // Add your code here
45     ++pick_planning_attempts;
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47 if (pick_success)
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Create a MoveGroupInterface and set the planning group

Hot Dog Pick

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Create a MoveGroupInterface and set the planning group

Use helper functions to get the pick and place poses

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Hot Dog Pick

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We want to plan and know if planning was successful

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Create a MoveGroupInterface and set the planning group

Use helper functions to get the pick and place poses

We want to plan to the pick pose

We want to plan and know if planning was successful

If we successfully planned, execute the plan

Hot Dog Pick

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28 MoveGroupInterface move_group_interface(node, planning_group);
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30 // Get predefined poses for pick and place above the sausage and bun respectively
31 const geometry_msgs::msg::Pose& pick_pose = hot_dog_scenario.getPickPose();
32 const geometry_msgs::msg::Pose& place_pose = hot_dog_scenario.getPlacePose();
33
34 // TODO(Exercise 1-1): Set the goal pose to the pick pose using MoveGroupInterface
35 // Add your code here
36
37 // Create a plan to that target pose
38 MoveGroupInterface::Plan pick_plan;
39 uint16_t pick_planning_attempts{ 0 };
40 bool pick_success{ false };
41 while (!pick_success && pick_planning_attempts < 5)
42 {
43     // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the pick pose and determine planning success
44     // Add your code here
45     ++pick_planning_attempts;
46 }
47 if (pick_success)
48 {
49     // Execute the plan
50     move_group_interface.execute(pick_plan);
```

Set the goal to **pick_pose**:

```
move_group_interface.setPoseTarget(pick_pose);
```

Hot Dog Pick

File: exercise1/src/exercise1-1/src/main.cpp

```
25 // Create the MoveGroupInterface
26 using moveit::planning_interface::MoveGroupInterface;
27 const std::string planning_group{ "ur_manipulator" };
28 MoveGroupInterface move_group_interface(node, planning_group);
29
30 // Get predefined poses for pick and place above the sausage and bun respectively
31 const geometry_msgs::msg::Pose& pick_pose = hot_dog_scenario.getPickPose();
32 const geometry_msgs::msg::Pose& place_pose = hot_dog_scenario.getPlacePose();
33
34 // TODO(Exercise 1-1): Set the goal pose to the pick pose using MoveGroupInterface
35 // Add your code here
36
37 // Create a plan to that target pose
38 MoveGroupInterface::Plan pick_plan;
39 uint16_t pick_planning_attempts{ 0 };
40 bool pick_success{ false };
41 while (!pick_success && pick_planning_attempts < 5)
42 {
43     // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the pick pose and determine planning success
44     // Add your code here
45     ++pick_planning_attempts;
46 }
47 if (pick_success)
48 {
49     // Execute the plan
50     move_group_interface.execute(pick_plan);
```

Set the goal to **pick_pose**:

```
move_group_interface.setPoseTarget(pick_pose);
```

Plan and determine if planning succeeded:

```
pick_success = static_cast<bool>(move_group_interface.plan(pick_plan));
```

Hot Dog Pick

File: exercise1/src/exercise1-1/src/main.cpp

```
25 // Create the MoveGroupInterface
26 using moveit::planning_interface::MoveGroupInterface;
27 const std::string planning_group{ "ur_manipulator" };
28 MoveGroupInterface move_group_interface(node, planning_group);
29
30 // Get predefined poses for pick and place above the sausage and bun respectively
31 const geometry_msgs::msg::Pose& pick_pose = hot_dog_scenario.getPickPose();
32 const geometry_msgs::msg::Pose& place_pose = hot_dog_scenario.getPlacePose();
33
34 // TODO(Exercise 1-1): Set the goal pose to the pick pose using MoveGroupInterface
35 // Add your code here
36
37 // Create a plan to that target pose
38 MoveGroupInterface::Plan pick_plan;
39 uint16_t pick_planning_attempts{ 0 };
40 bool pick_success{ false };
41 while (!pick_success && pick_planning_attempts < 5)
42 {
43     // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the pick pose and determine planning success
44     // Add your code here
45     ++pick_planning_attempts;
46 }
47 if (pick_success)
48 {
49     // Execute the plan
50     move_group_interface.execute(pick_pl
```

Set the goal to `pick_pose`:

```
move_group_interface.setPoseTarget(pick_pose);
```

Plan and determine if planning succeeded:

```
pick_success = static_cast<bool>(move_group_interface.plan(pick_plan));
```

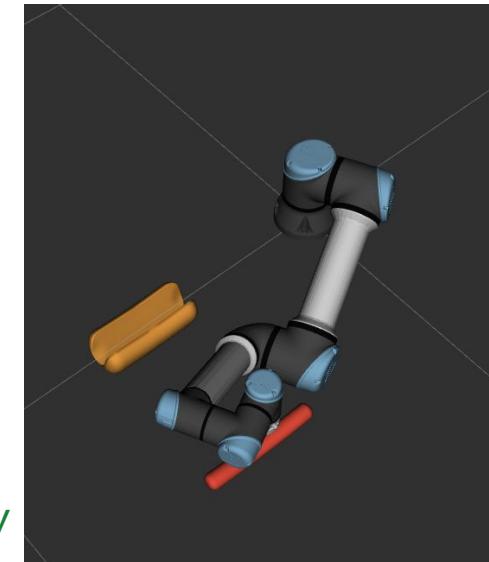
Terminal 1: \$ colcon build

Terminal 1: \$ ros2 launch exercise1-1 ur.launch.py

Terminal 2: \$ ros2 launch exercise1-1 exercise1-1.launch.py

Hot Dog Pick

- **Terminal 1:** Rebuild and restart the UR mock
 - `$ colcon build`
 - `$ ros2 launch exercise1-1 ur.launch.py`
- **Terminal 2:** Run the modified exercise 1-1:
 - `$ ros2 launch exercise1-1 exercise1-1.launch.py`
- Watch the robot plan and move to the sausage in RViz
 - It may take a roundabout path due to RRTConnect
 - If you want to watch it again, or if planning fails, stop the UR mock with **Ctrl+C** and restart:
 - **Terminal 1:** `$ ros2 launch exercise1-1 ur.launch.py`
 - **Terminal 2:** `$ ros2 launch exercise1-1 exercise1-1.launch.py`
- Stop the UR mock with **Ctrl+C** when done



Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

Helper function to get the sausage collision object

```
52 const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54 // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55 // Add your code to attach the sausage here  
56 // Add your code to set the goal pose here  
57  
58 MoveGroupInterface::Plan place_plan;  
59 uint16_t place_planning_attempts{ 0 };  
60 bool place_success{ false };  
61 while (!place_success && place_planning_attempts < 5)  
{  
    // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
    // Add your code here  
    ++place_planning_attempts;  
}  
67  
68 // Execute the plan  
69 if (place_success)  
{  
    move_group_interface.execute(place_plan);  
}
```

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52 const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54 // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55 // Add your code to attach the sausage here  
56 // Add your code to set the goal pose here  
57  
58 MoveGroupInterface::Plan place_plan;  
59 uint16_t place_planning_attempts{ 0 };  
60 bool place_success{ false };  
61 while (!place_success && place_planning_attempts < 5)  
{  
    // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
    // Add your code here  
    ++place_planning_attempts;  
}  
67  
68 // Execute the plan  
69 if (place_success)  
{  
    move_group_interface.execute(place_plan);  
}
```

Helper function to get the sausage collision object

We want to pick up the sausage and plan to the place pose

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52 const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54 // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55 // Add your code to attach the sausage here  
56 // Add your code to set the goal pose here  
57  
58 MoveGroupInterface::Plan place_plan;  
59 uint16_t place_planning_attempts{ 0 };  
60 bool place_success{ false };  
61 while (!place_success && place_planning_attempts < 5)  
{  
62     // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
63     // Add your code here  
64     ++place_planning_attempts;  
65 }  
66  
67 // Execute the plan  
68 if (place_success)  
{  
69     move_group_interface.execute(place_plan);  
70 }  
71  
72 }
```

Helper function to get the sausage collision object

We want to pick up the sausage and plan to the place pose

We want to create a motion plan and know if planning was successful

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52     const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();
53
54     // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose
55     // Add your code to attach the sausage here
56     // Add your code to set the goal pose here
57
58     MoveGroupInterface::Plan place_plan;
59     uint16_t place_planning_attempts{ 0 };
60     bool place_success{ false };
61     while (!place_success && place_planning_attempts < 5)
62     {
63         // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success
64         // Add your code here
65         ++place_planning_attempts;
66     }
67
68     // Execute the plan
69     if (place_success)
70     {
71         move_group_interface.execute(place_plan);
72     }
```

Attach the sausage collision object

```
move_group_interface.attachObject(sausage.id);
```

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52     const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54     // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55     // Add your code to attach the sausage here  
56     // Add your code to set the goal pose here  
57  
58     MoveGroupInterface::Plan place_plan;  
59     uint16_t place_planning_attempts{ 0 };  
60     bool place_success{ false };  
61     while (!place_success && place_planning_attempts < 5)  
62     {  
63         // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
64         // Add your code here  
65         ++place_planning_attempts;  
66     }  
67  
68     // Execute the plan  
69     if (place_success)  
70     {  
71         move_group_interface.execute(place_plan);  
72     }
```

const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();

// TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose

// Add your code to attach the sausage here

// Add your code to set the goal pose here

Attach the sausage collision object

```
move_group_interface.attachObject(sausage.id);
```

Set the planning goal to place_pose:

```
move_group_interface.setPoseTarget(place_pose);
```

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52     const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54     // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55     // Add your code to attach the sausage here  
56     // Add your code to set the goal pose here  
57  
58     MoveGroupInterface::Plan place_plan;  
59     uint16_t place_planning_attempts{ 0 };  
60     bool place_success{ false };  
61     while (!place_success && place_planning_attempts < 5)  
62     {  
63         // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
64         // Add your code here  
65         ++place_planning_attempts;  
66     }  
67  
68     // Execute the plan  
69     if (place_success)  
70     {  
71         move_group_interface.execute(place_plan);  
72     }
```

Diagram annotations:

- Annotation 1: A callout box with a red arrow pointing to the line `// Add your code to attach the sausage here`. It contains the text "Attach the sausage collision object" and the code `move_group_interface.attachObject(sausage.id);`.
- Annotation 2: A callout box with a red arrow pointing to the line `// Add your code to set the goal pose here`. It contains the text "Set the planning goal to `place_pose`:" and the code `move_group_interface.setPoseTarget(place_pose);`.
- Annotation 3: A callout box with a red arrow pointing to the line `// Add your code here` inside the loop. It contains the text "Plan and determine if planning succeeded:" and the code `place_success = static_cast<bool>(move_group_interface.plan(place_plan));`.

Hot Dog Place

File: exercise1/src/exercise1-1/src/main.cpp

```
52     const moveit_msgs::msg::CollisionObject& sausage = hot_dog_scenario.getSausage();  
53  
54     // TODO(Exercise 1-1): Attach the sausage to the robot and plan to the place pose  
55     // Add your code to attach the sausage here  
56     // Add your code to set the goal pose here  
57  
58     MoveGroupInterface::Plan place_plan;  
59     uint16_t place_planning_attempts{ 0 };  
60     bool place_success{ false };  
61     while (!place_success && place_planning_attempts < 5)  
62     {  
63         // TODO(Exercise 1-1): Use MoveGroupInterface to plan to the place pose and determine planning success  
64         // Add your code here  
65         ++place_planning_attempts;  
66     }  
67  
68     // Execute the plan  
69     if (place_success)  
70     {  
71         move_group  
72     }
```

Attach the sausage collision object
`move_group_interface.attachObject(sausage.id);`

Set the planning goal to `place_pose`:
`move_group_interface.setPoseTarget(place_pose);`

Plan and determine if planning succeeded:
`place_success = static_cast<bool>(move_group_interface.plan(place_plan));`

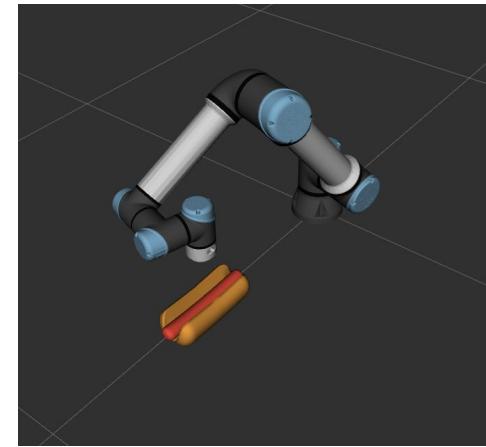
Terminal 1: \$ colcon build

Terminal 1: \$ ros2 launch exercise1-1 ur.launch.py

Terminal 2: \$ ros2 launch exercise1-1 exercise1-1.launch.py

Running the Pick and Place

- **Terminal 1:** Rebuild and restart the UR mock
 - `$ colcon build`
 - `$ ros2 launch exercise1-1 ur.launch.py`
- **Terminal 2:** Run the modified exercise 1-1:
 - `$ ros2 launch exercise1-1 exercise1-1.launch.py`
- Watch the robot plan and move to the sausage, pick it up, plan and move to the bun, and drop the sausage down in RViz
 - It may take a roundabout path due to RRTConnect
 - If you want to watch it again, or if planning fails, stop the UR mock with **Ctrl+C** and restart:
 - **Terminal 1:** `$ ros2 launch exercise1-1 ur.launch.py`
 - **Terminal 2:** `$ ros2 launch exercise1-1 exercise1-1.launch.py`
- Stop the UR mock with **Ctrl+C** when done



Hot Dog Pick and Place

- Congrats on building a pick and place application!
- General flow:
 - Move to pick location
 - Pick up the object
 - Move to place location
 - Place the object
- How do we actually place the object? Let's walk through the last lines of code together.

Final Touches

File: exercise1/src/exercise1-1/src/main.cpp

```
78 // Detach the hot dog
79 move_group_interface.detachObject(sausage.id);
80 if (place_success)
81 {
82     // Drop the hot dog down into the bun
83     hot_dog_scenario.placeSausage();
84 }
85 }
```

Detach the sausage collision object from
the end effector



Final Touches

File: exercise1/src/exercise1-1/src/main.cpp

```
78 // Detach the hot dog  
79 move_group_interface.detachObject(sausage.id);  
80 if (place_success)  
81 {  
82     // Drop the hot dog down into the bun  
83     hot_dog_scenario.placeSausage();  
84 }  
85 }
```

Detach the sausage collision object from the end effector

Don't drop the hot dog into the bun if we failed to plan the place motion

Final Touches

File: exercise1/src/exercise1-1/src/main.cpp

```
78 // Detach the hot dog  
79 move_group_interface.detachObject(sausage.id);  
80 if (place_success)  
81 {  
82     // Drop the hot dog down into the bun  
83     hot_dog_scenario.placeSausage();  
84 }  
85 }
```

Detach the sausage collision object from the end effector

Don't drop the hot dog into the bun if we failed to plan the place motion

Helper function that lets us drop the hot dog into the bun

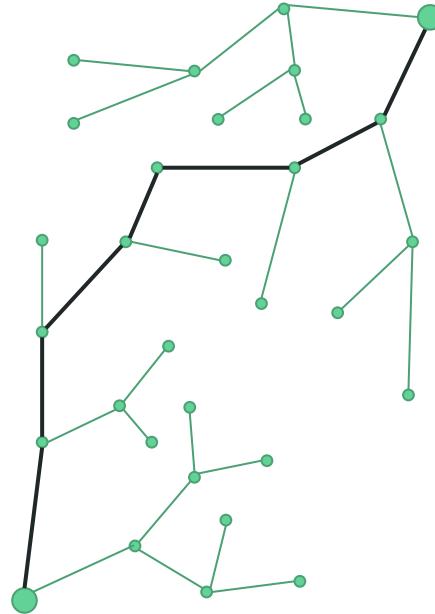
What's missing?

- This example is somewhat simplified from real life, as it doesn't contain a gripper. This allows us to simplify some of the nuances of grasping
- More general flow for a typical pick and place application:
 - Move to a pre-pick location
 - Allow collisions with the object to pick
 - Cartesian move from pre-pick to grasp
 - Close gripper
 - Pick up the object
 - Cartesian retreat
 - Move to pre-place location
 - Cartesian move from pre-place to place
 - Place the object
 - Cartesian retreat
 - Forbid collisions with the object
- Exercise 1-2 will cover Cartesian planning

Exercise 1-2: Hot Dog Cartesian Planning

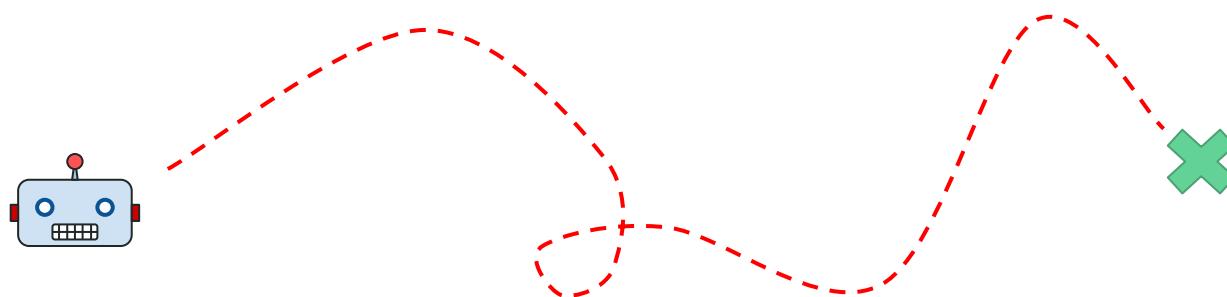
RRTConnect

- Did anyone see the robot go an unexpected direction (backward, twisting unnecessarily, under the hotdog, etc.)?
- Default planner is OMPL RRTConnect
 - Connects two trees that randomly expand
 - Fast, good at finding a solution, non-deterministic, does not return “best” path
- Can configure your planner with:
 - `move_group_interface.setPlannerId(planner_id)`
- Try different planners and see how they perform!



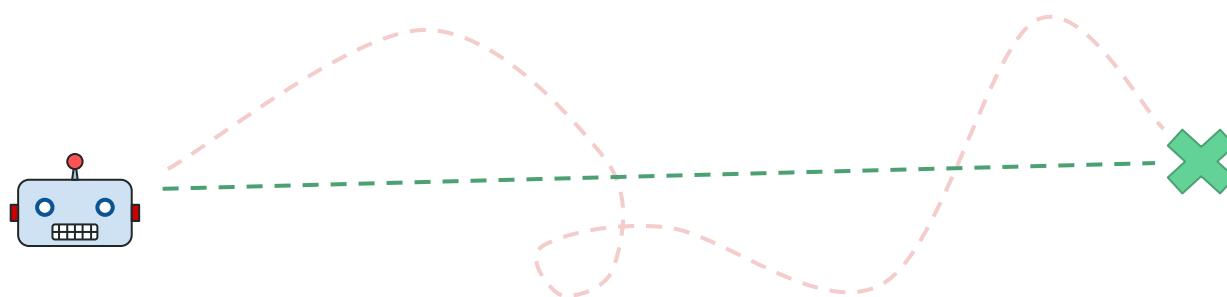
Hot Dog Cartesian Planning

- In this example, we'd like to apply mustard to our hot dog
- Wild motions from are not a particularly good fit for applying mustard
 - What a mess!
 - Want a controlled path that moves in predictable, straight lines
- Let's use Cartesian planning!



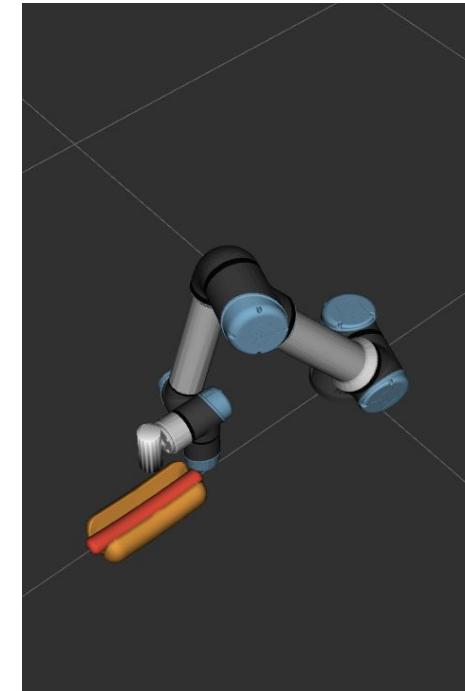
Hot Dog Cartesian Planning

- In this example, we'd like to apply mustard to our hot dog
- Wild motions from are not a particularly good fit for applying mustard
 - What a mess!
 - Want a controlled path that moves in predictable, straight lines
- Let's use Cartesian planning!



Hot Dog Cartesian Planning

- **Terminal 1:** Restart the UR mock (same as in `exercise1-1`):
 - `$ ros2 launch exercise1-2 ur.launch.py`
- **Terminal 2:** Start exercise 1-2:
 - `$ ros2 launch exercise1-2 exercise1-2.launch.py`
- Should see:
 - The assembled hot dog from exercise 1-1
 - The robot holding a mustard bottle
 - The robot should plan and move to just above the hot dog to apply mustard
- Stop all processes with **Ctrl+C**
- Let's make Cartesian moves!



Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
26 // Create the MoveGroupInterface
27 using moveit::planning_interface::MoveGroupInterface;
28 const std::string planning_group{ "ur_manipulator" };
29 MoveGroupInterface move_group_interface(node, planning_group);
30
31 // A pose just above the bun
32 const auto& start_pose = hot_dog_scenario.getStartPose();
33 move_group_interface.setPoseTarget(start_pose);
34
35 MoveGroupInterface::Plan start_plan;
36 bool success{ false };
37 uint16_t attempts{ 0 };
38 while (!success && attempts < 5)
39 {
40     success = static_cast<bool>(move_group_interface.plan(start_plan));
41     ++attempts;
42 }
43
44 if (success)
45 {
46     move_group_interface.execute(start_plan);
```

Create a MoveGroupInterface and set the planning group

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
26 // Create the MoveGroupInterface
27 using moveit::planning_interface::MoveGroupInterface;
28 const std::string planning_group{ "ur_manipulator" };
29 MoveGroupInterface move_group_interface(node, planning_group);
30
31 // A pose just above the bun
32 const auto& start_pose = hot_dog_scenario.getStartPose();
33 move_group_interface.setPoseTarget(start_pose);
34
35 MoveGroupInterface::Plan start_plan;
36 bool success{ false };
37 uint16_t attempts{ 0 };
38 while (!success && attempts < 5)
39 {
40     success = static_cast<bool>(move_group_interface.plan(start_plan));
41     ++attempts;
42 }
43
44 if (success)
45 {
46     move_group_interface.execute(start_plan);
```

Create a MoveGroupInterface and set the planning group

Use helper method to get the pose just above the hot dog

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
26 // Create the MoveGroupInterface
27 using moveit::planning_interface::MoveGroupInterface;
28 const std::string planning_group{ "ur_manipulator" };
29 MoveGroupInterface move_group_interface(node, planning_group);
30
31 // A pose just above the bun
32 const auto& start_pose = hot_dog_scenario.getStartPose();
33 move_group_interface.setPoseTarget(start_pose);
34
35 MoveGroupInterface::Plan start_plan;
36 bool success{ false };
37 uint16_t attempts{ 0 };
38 while (!success && attempts < 5)
39 {
40     success = static_cast<bool>(move_group_interface.plan(start_plan));
41     ++attempts;
42 }
43
44 if (success)
45 {
46     move_group_interface.execute(start_plan);
```

Create a MoveGroupInterface and set the planning group

Use helper method to get the pose just above the hot dog

Set that pose as the planning goal

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
26 // Create the MoveGroupInterface  
27 using moveit::planning_interface::MoveGroupInterface;  
28 const std::string planning_group{ "ur_manipulator" };  
29 MoveGroupInterface move_group_interface(node, planning_group);  
30  
31 // A pose just above the bun  
32 const auto& start_pose = hot_dog_scenario.getStartPose();  
33 move_group_interface.setPoseTarget(start_pose);  
34  
35 MoveGroupInterface::Plan start_plan;  
36 bool success{ false };  
37 uint16_t attempts{ 0 };  
38 while (!success && attempts < 5)  
39 {  
40     success = static_cast<bool>(move_group_interface.plan(start_plan));  
41     ++attempts;  
42 }  
43  
44 if (success)  
45 {  
46     move_group_interface.execute(start_plan);  
47 }
```

Create a MoveGroupInterface and set the planning group

Use helper method to get the pose just above the hot dog

Set that pose as the planning goal

Solve for a motion plan (similarly to exercise 1-1) and check for success

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
26 // Create the MoveGroupInterface  
27 using moveit::planning_interface::MoveGroupInterface;  
28 const std::string planning_group{ "ur_manipulator" };  
29 MoveGroupInterface move_group_interface(node, planning_group);  
30  
31 // A pose just above the bun  
32 const auto& start_pose = hot_dog_scenario.getStartPose();  
33 move_group_interface.setPoseTarget(start_pose);  
34  
35 MoveGroupInterface::Plan start_plan;  
36 bool success{ false };  
37 uint16_t attempts{ 0 };  
38 while (!success && attempts < 5)  
39 {  
40     success = static_cast<bool>(move_group_interface.plan(start_plan));  
41     ++attempts;  
42 }  
43  
44 if (success)  
45 {  
46     move_group_interface.execute(start_plan);
```

Create a MoveGroupInterface and set the planning group

Use helper method to get the pose just above the hot dog

Set that pose as the planning goal

Solve for a motion plan (similarly to exercise 1-1) and check for success

Execute if successful and move just above the hot dog, ready to apply mustard

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

Helper method to get a vector of poses in a zig-zag to apply our mustard

```
48 const std::vector<geometry_msgs::msg::Pose> waypoints = hot_dog_scenario.getMustardWaypoints(start_pose);
49
50 moveit_msgs::msg::RobotTrajectory trajectory;
51
52 // TODO(Exercise 1-2): Plan a Cartesian path
53 double fraction = 0;
54
55 if (fraction > 0)
56 {
57     move_group_interface.execute(trajectory);
58     hot_dog_scenario.applyMustard();
59 }
```

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

Helper method to get a vector of poses in a zig-zag to apply our mustard

```
48 const std::vector<geometry_msgs::msg::Pose> waypoints = hot_dog_scenario.getMustardWaypoints(start_pose);  
49  
50 moveit_msgs::msg::RobotTrajectory trajectory;  
51  
52 // TODO(Exercise 1-2): Plan a Cartesian path ←  
53 double fraction = 0;  
54  
55 if (fraction > 0)  
56 {  
57     move_group_interface.execute(trajectory);  
58     hot_dog_scenario.applyMustard();  
59 }
```

We want to create a Cartesian plan through our list of poses and we want to know what fraction of the path we were successful in planning

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
48 const std::vector<geometry_msgs::msg::Pose> waypoints = hot_dog_scenario.getMustardWaypoints(start_pose);  
49  
50 moveit_msgs::msg::RobotTrajectory trajectory;  
51  
52 // TODO(Exercise 1-2): Plan a Cartesian path ←  
53 double fraction = 0;  
54  
55 if (fraction > 0)  
56 {  
57     move_group_interface.execute(trajectory); ←  
58     hot_dog_scenario.applyMustard();  
59 }
```

Helper method to get a vector of poses in a zig-zag to apply our mustard

We want to create a Cartesian plan through our list of poses and we want to know what fraction of the path we were successful in planning

Execute the trajectory to apply mustard!

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

```
48 const std::vector<geometry_msgs::msg::Pose> waypoints = hot_dog_scenario.getMustardWaypoints(start_pose);  
49  
50 moveit_msgs::msg::RobotTrajectory trajectory;  
51  
52 // TODO(Exercise 1-2): Plan a Cartesian path ←  
53 double fraction = 0;  
54  
55 if (fraction > 0)  
56 {  
57     move_group_interface.execute(trajectory);  
58     hot_dog_scenario.applyMustard();  
59 }
```

Helper method to get a vector of poses in a zig-zag to apply our mustard

We want to create a Cartesian plan through our list of poses and we want to know what fraction of the path we were successful in planning

Execute the trajectory to apply mustard!

Helper method to show mustard visualization

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

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48 const std::vector<geometry_msgs::msg::Pose> waypoints = hot_dog_scenario.getMustardWaypoints(start_pose);  
49  
50 moveit_msgs::msg::RobotTrajectory trajectory;  
51  
52 // TODO(Exercise 1-2): Plan a Cartesian path  
53 double fraction = 0; ← Remove the 0 and replace it with:  
54  
55 if (fraction > 0)  
56 {  
57     move_group_interface.execute(trajectory);  
58     hot_dog_scenario.applyMustard();  
59 }
```

Remove the 0 and replace it with:

```
move_group_interface.computeCartesianPath(waypoints,  
0.002, 1.5, trajectory);
```

Hot Dog Cartesian Planning

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```

Terminal 1: \$ colcon build

Terminal 1: \$ ros2 launch exercise1-2 ur.launch.py

Terminal 2: \$ ros2 launch exercise1-2 exercise1-2.launch.py

Hot Dog Cartesian Planning

File: exercise1/src/exercise1-2/src/main.cpp

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eef_step defines the distance in meters between end effector configurations of consecutive points in the result trajectory

Terminal 1: \$ colcon build

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Hot Dog Cartesian Planning

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Remove the 0 and replace it with:

```
move_group_interface.computeCartesianPath(waypoints,  
0.002, 1.5, trajectory);
```

eef_step defines the distance in meters between end effector configurations of consecutive points in the result trajectory

jump_threshold limits joint space jumps, which can be large even if the Cartesian distance between the points is small

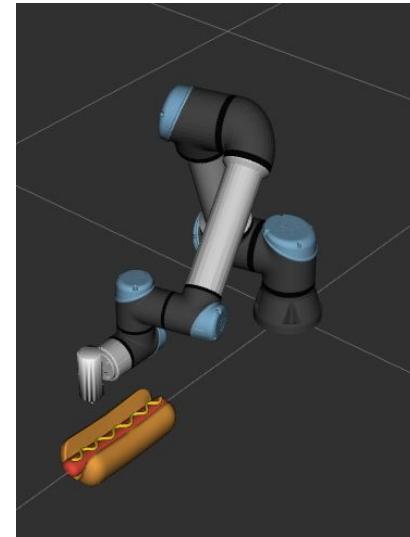
Terminal 1: \$ colcon build

Terminal 1: \$ ros2 launch exercise1-2 ur.launch.py

Terminal 2: \$ ros2 launch exercise1-2 exercise1-2.launch.py

Running the Cartesian Planning Example

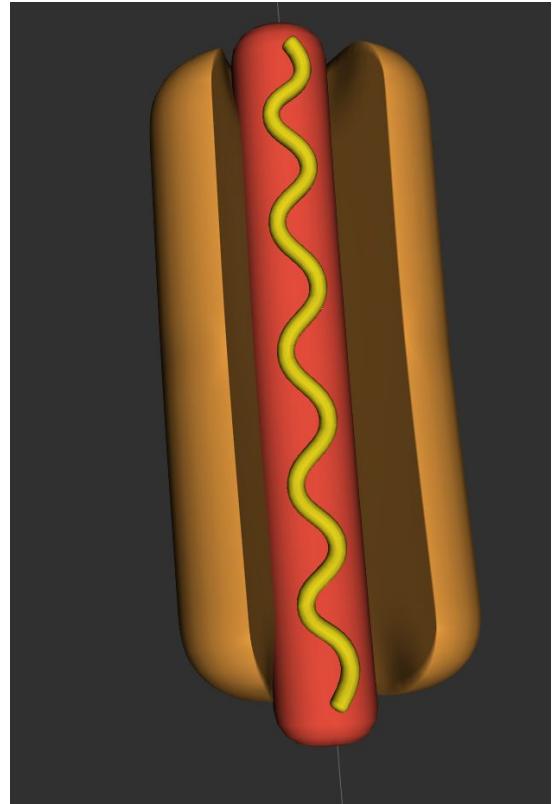
- Rebuild:
 - `$ colcon build`
- Restart the UR mock:
 - `$ ros2 launch exercise1-2 ur.launch.py`
- Run the modified exercise 1-2:
 - `$ ros2 launch exercise1-2 exercise1-2.launch.py`
- Robot should plan and move to the hot dog using RRTConnect, then move through the mustard zig-zag with Cartesian motions
 - If you want to watch it again, or if planning fails, stop the UR mock with Ctrl+C and restart:
 - **Terminal 1:** `$ ros2 launch exercise1-2 ur.launch.py`
 - **Terminal 2:** `$ ros2 launch exercise1-2 exercise1-2.launch.py`
- Stop the UR mock with **Ctrl+C** when done



Exercise 1 Summary

What did we learn?

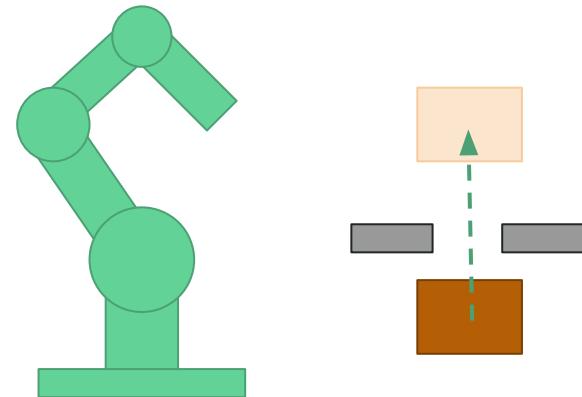
- We used MoveIt's MoveGroupInterface to make motion plans
 - Set the goal pose
 - Plan, check for success, and execute
 - Attaching collision objects
 - Detaching collision objects
- We also use MoveGroupInterface to make Cartesian motion plans
 - Complex planners might not be necessary for some problems
 - Cartesian interpolator can be used for straight-line motions



And now?

Most tasks consist of a series of motion plans

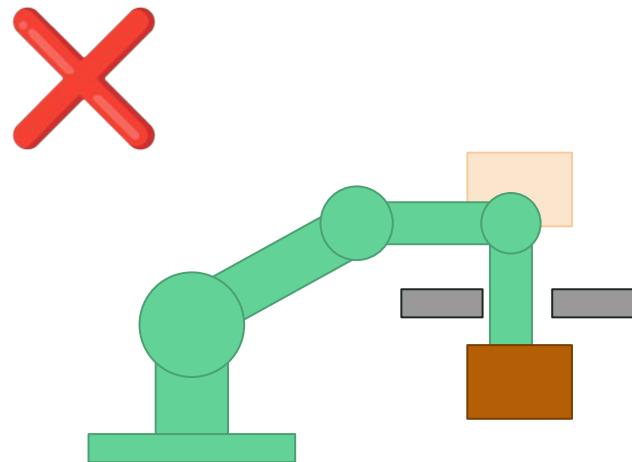
- Plan, if successful, plan again, if successful, plan again...
- What happens if we fail to plan part way through?
- What happens if we plan to a joint state that makes the next motion difficult or impossible?



And now?

Most tasks consist of a series of motion plans

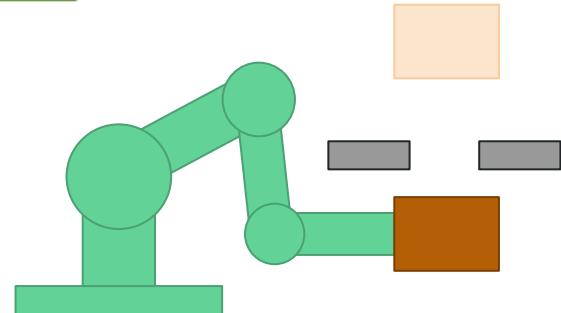
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And now?

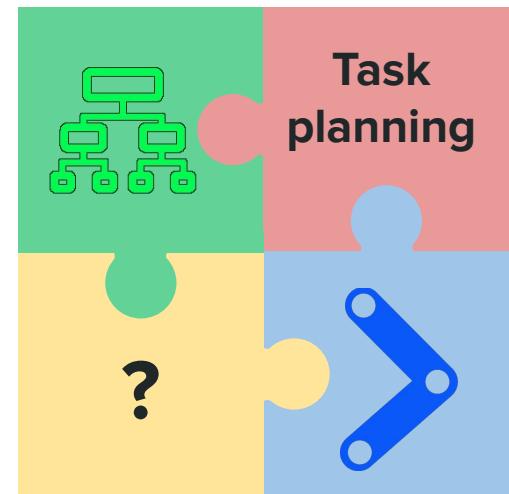
Most tasks consist of a series of motion plans

- Plan, if successful, plan again, if successful, plan again...
- What happens if we fail to plan part way through?
- What happens if we plan to a joint state that makes the next motion difficult or impossible?



Motion Planning and Manipulation

- Movelt is a **motion planning** framework
 - Enables you to create motion plans to move your robot from one point to another
- Manipulation tasks generally require a series of connected motions and motion plans
 - Pick and place, material handling, packaging, assembly...
- Motion planning can and will fail
 - Reliable systems require logic to handle failures
- Movelt is one piece of the manipulation puzzle



Manipulation is not just Motion Planning

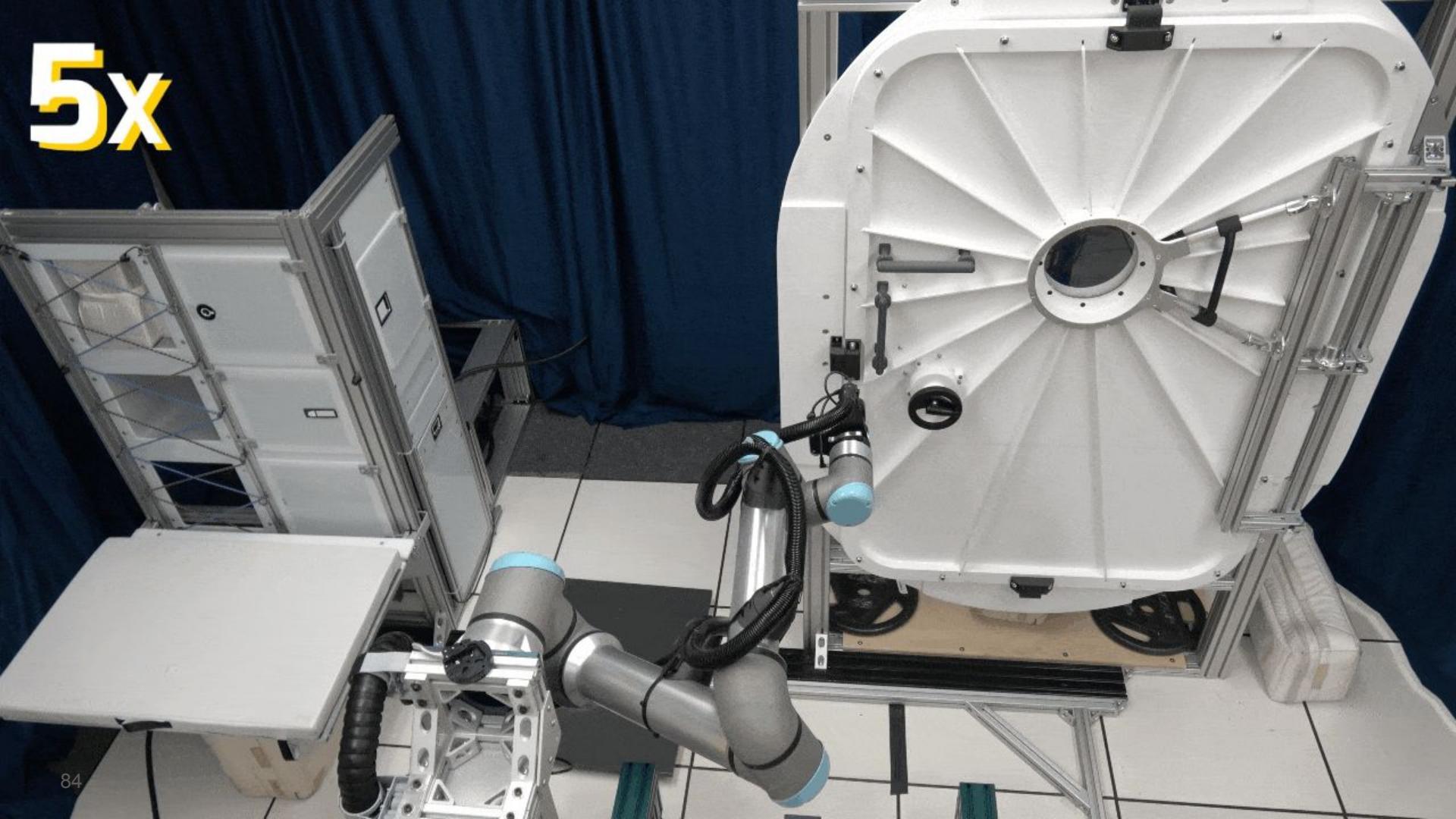
Motion Planning != Manipulation

What is Motion Planning?

“Motion planning is the problem of finding a robot motion from a start state to a goal state that avoids obstacles in the environment and satisfies other constraints”
(Lynch, K. M., & Park, F. C. (2017))

Robotic manipulation involves technical approaches that enable robots to interact with objects in the real world, including **sensor processing**, **visual perception**, **higher level reasoning**, **motion controls**, **modeling of process dynamics**, and **error handling**.

5x



Manipulation Challenges (Example)

- **High-level runtime logic**
 - integrates all these components and enables error handling
- **Force sensing & Perception**
 - detecting objects, door, valve, door handle
 - noticing when valve is open or closed
- **Controller Switching**
 - some trajectories need to tolerate external and unpredictable forces using admittance/impedance control
 - opening and closing of door and lid, turning of valve
 - some paths can be controlled in Cartesian space, others in joint space
- **Multi-step Motion Planning**
 - rearranging the arm while opening and closing the door

Manipulation Challenges - Technical Approaches

- High-level runtime logic
 - → **BT.CPP**
- Force sensing & Perception
 - → **ROS + BT.CPP**
- Controller Switching
 - → **ros2_control**
- Multi-step Motion Planning
 - → **Movelt Task Constructor**

Movelt is Single Source of Truth (SSOT) for robot and scene models used for motion planning.

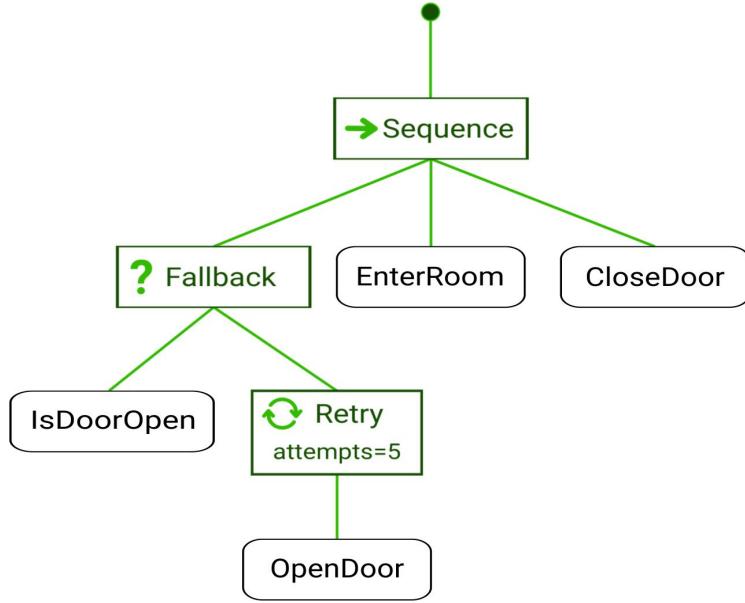
Runtime Logic - Behavior Trees

Behavior trees

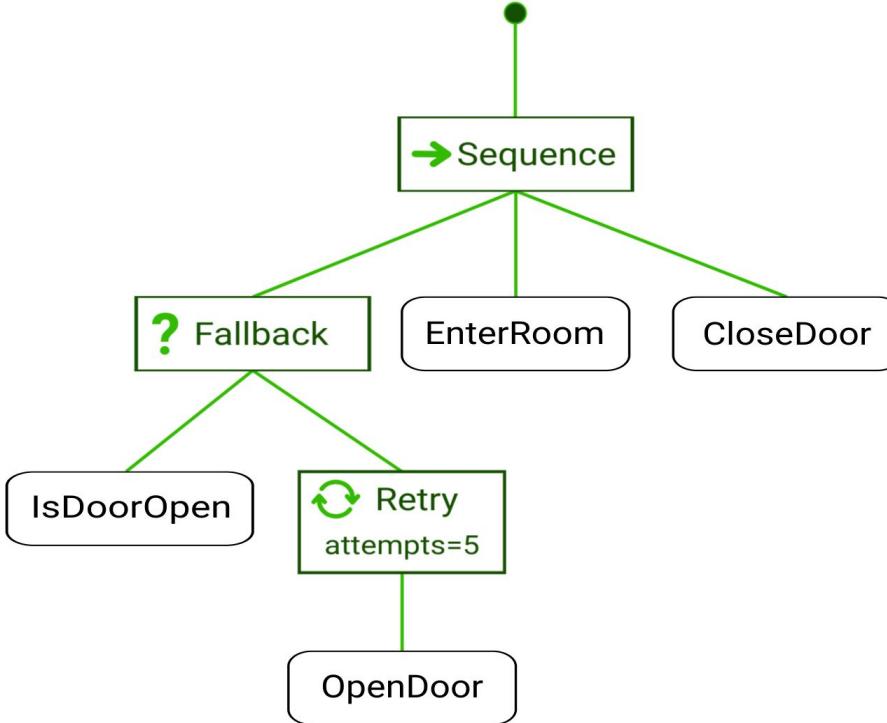
- model hierarchical behaviors as composable trees
- tree nodes are runtime actions which are executed (*=ticked*) iteratively
- action ticks return SUCCESS, RUNNING, FAILURE
- data is shared through key-value blackboard

Movelt Pro uses the **BehaviorTree.CPP** library

- great ROS compatibility
- simple XML file structure



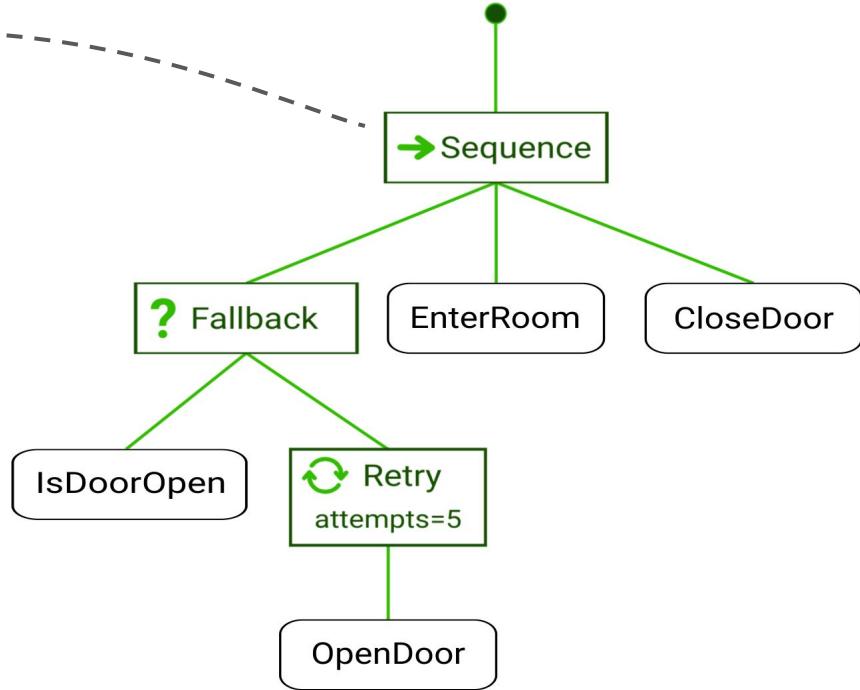
Runtime Logic - Behavior Trees



Runtime Logic - Behavior Trees

ControlNode

- controls ticking of multiple child nodes



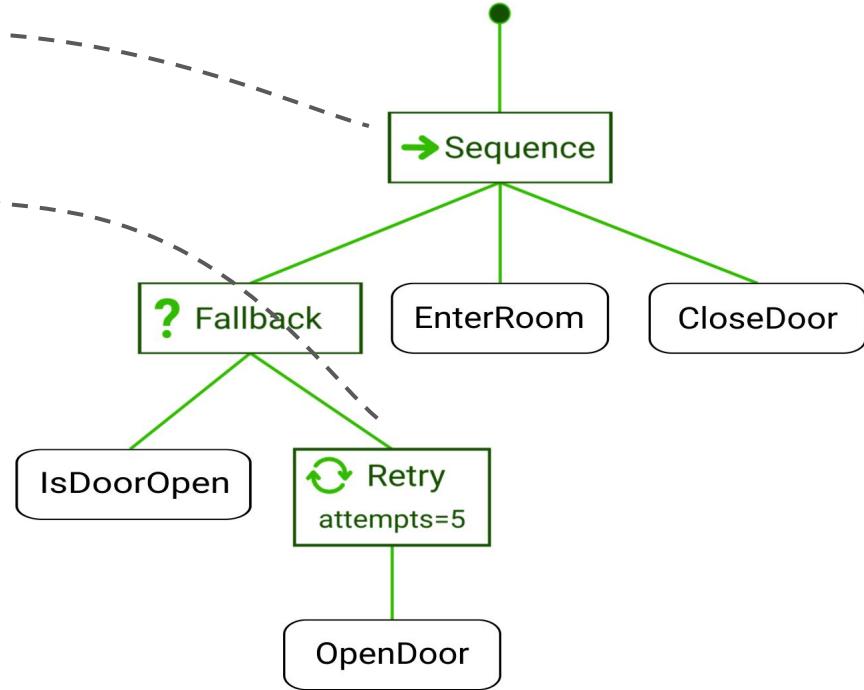
Runtime Logic - Behavior Trees

ControlNode

- controls ticking of multiple child nodes

DecoratorNode

- ticks and processes result of single child node



Runtime Logic - Behavior Trees

ControlNode

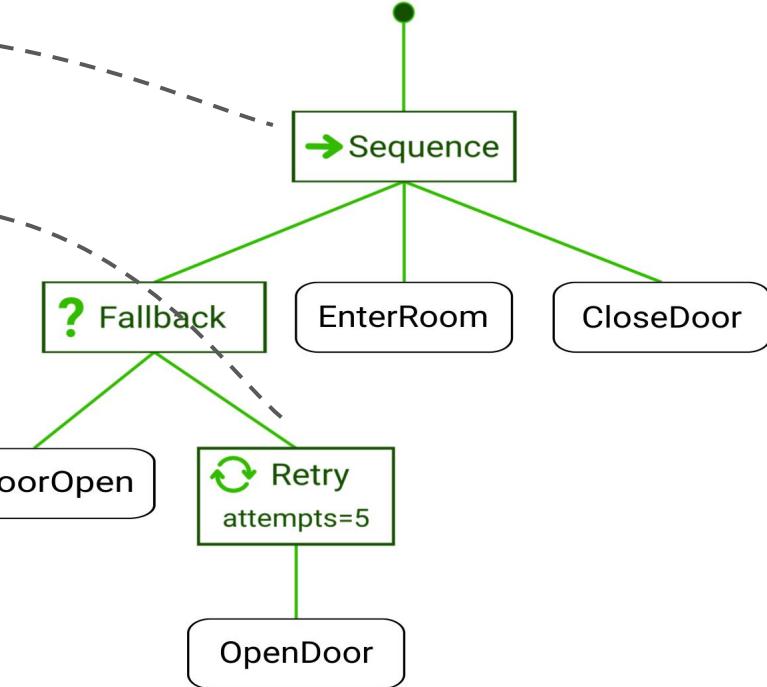
- controls ticking of multiple child nodes

DecoratorNode

- ticks and processes result of single child node

ConditionNode

- evaluates a condition, no child nodes



Runtime Logic - Behavior Trees

ControlNode

- controls ticking of multiple child nodes

DecoratorNode

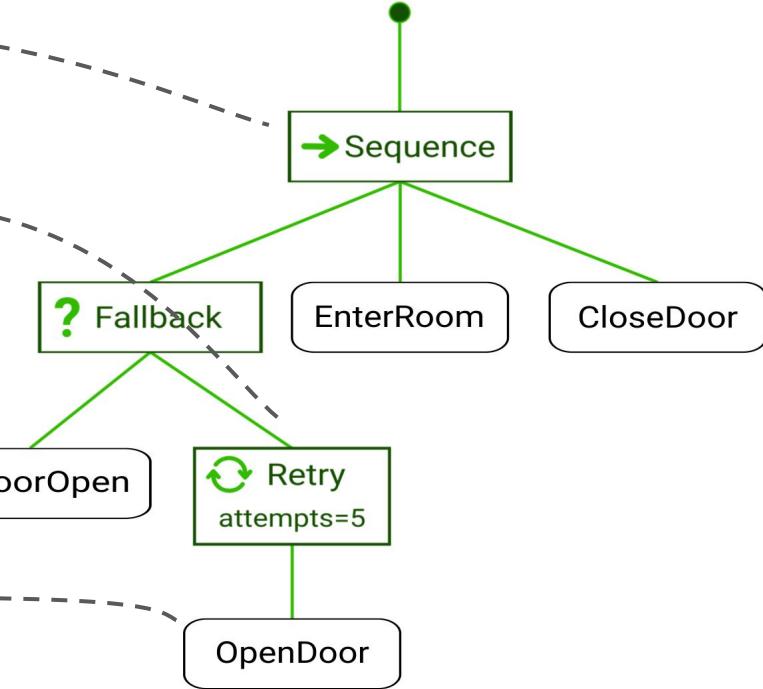
- ticks and processes result of single child node

ConditionNode

- evaluates a condition, no child nodes

ActionNode

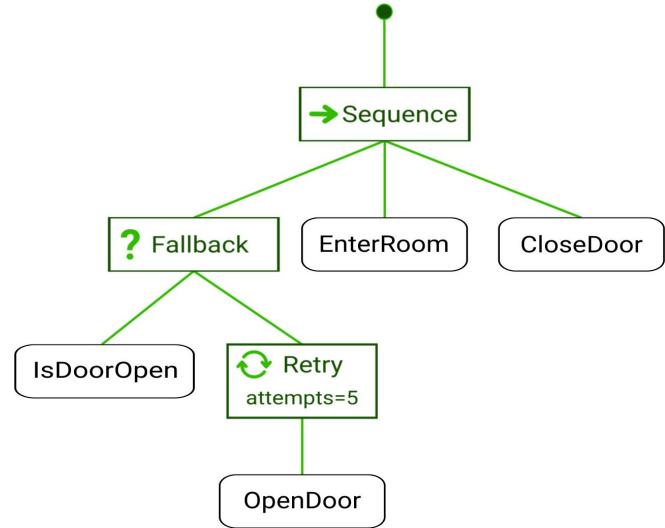
- “does something”, no child nodes



Runtime Logic - Why Behavior Trees?

There are many powerful alternatives

- Decision Trees, Finite State Machines, ...
- potentially more “expressive” or “elegant” for some applications

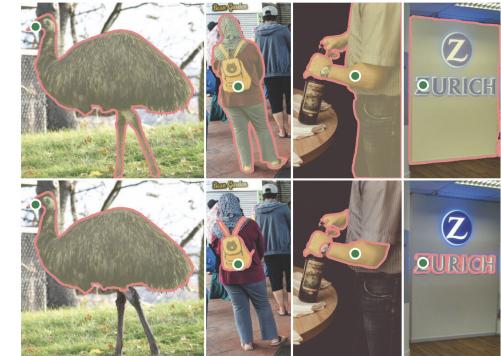


Behavior Trees excel in modeling **reactive** systems and enable more **intuitive** visual representations.

Integrating sensor and vision feedback

ROS message interfaces already provide a great solution for this!

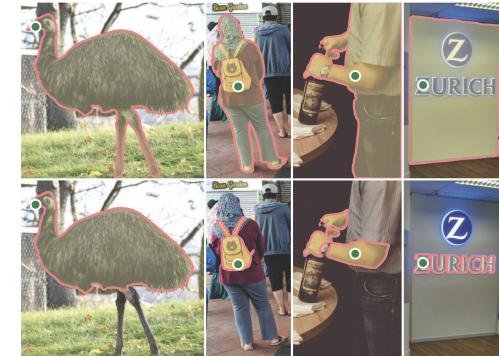
- isolate sensor/perception in separate ROS nodes
- use ROS interfaces for consuming data



Integrating sensor and vision feedback

With BT.CPP you can

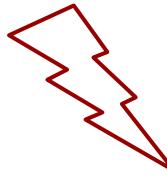
- implement topic/service/action client inside *actions*
- share processed data with the remaining logic via *blackboard*



Integrating sensor and vision feedback

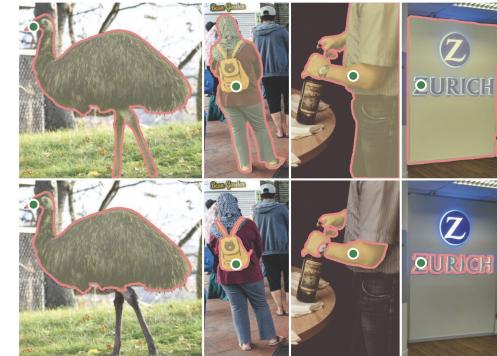
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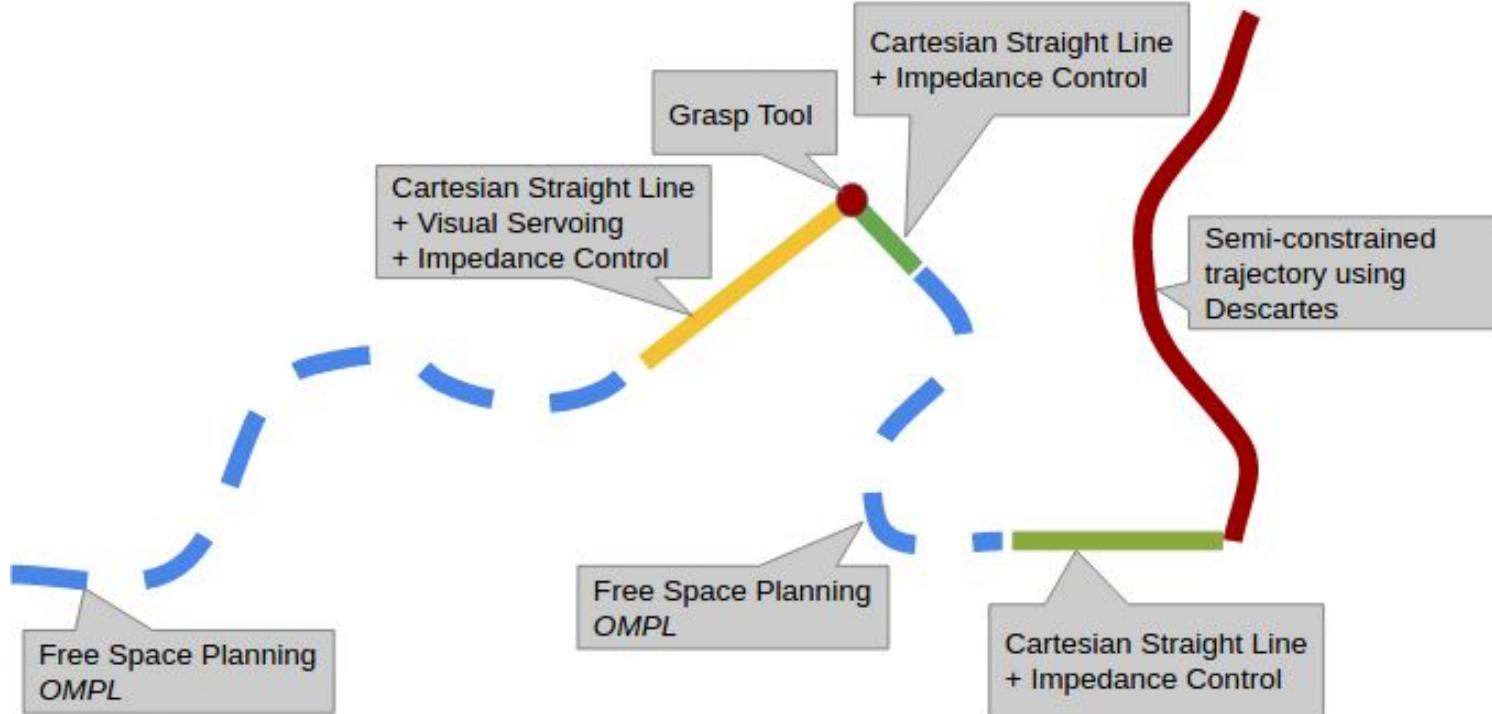


ROS + BT.CPP solves a very common design problem:

- decouples application logic and ROS interfaces, facilitating refactoring and mock testing



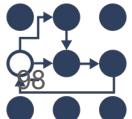
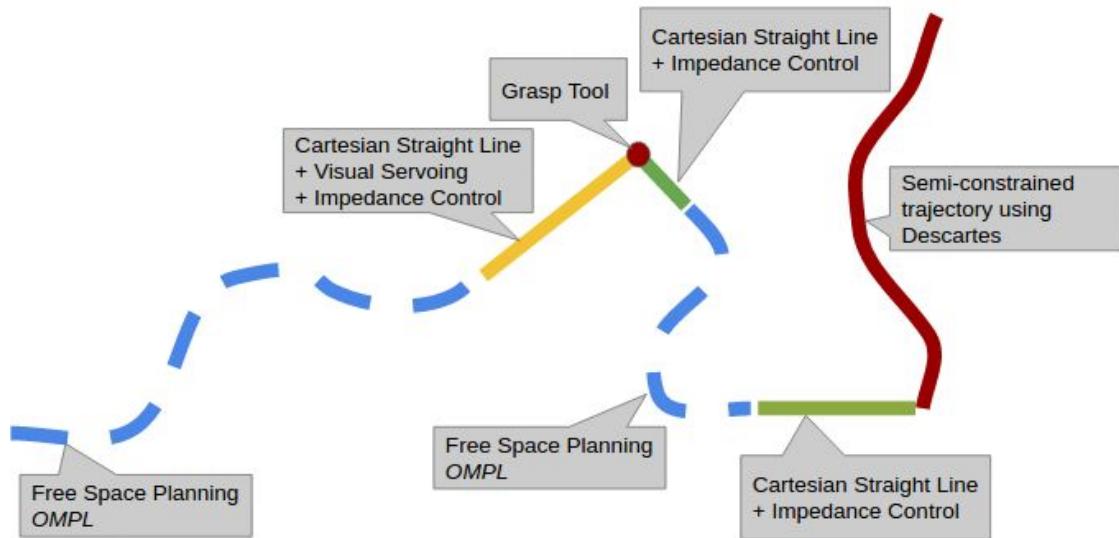
Controller Switching - Why?



Controller Switching - ros2_control

ros2_control

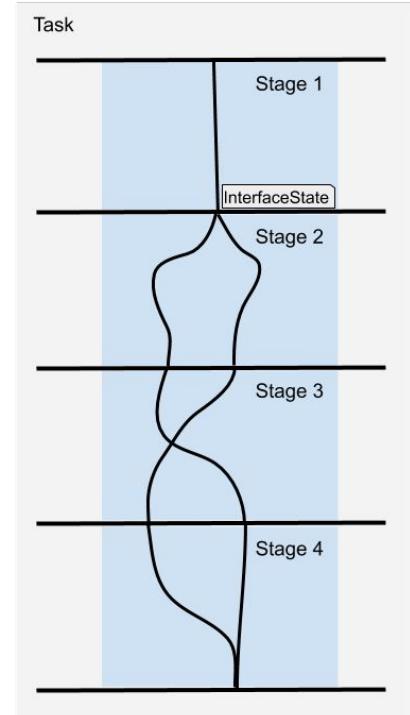
- framework for managing hardware resources and controllers
- multiple controllers can be configured and registered for the same hardware
- conflict-free (de)activation or “switching” of controllers is realized using a ROS service



Multi-step Motion Planning - Moveit Task Constructor

Moveit Task Constructor (MTC)

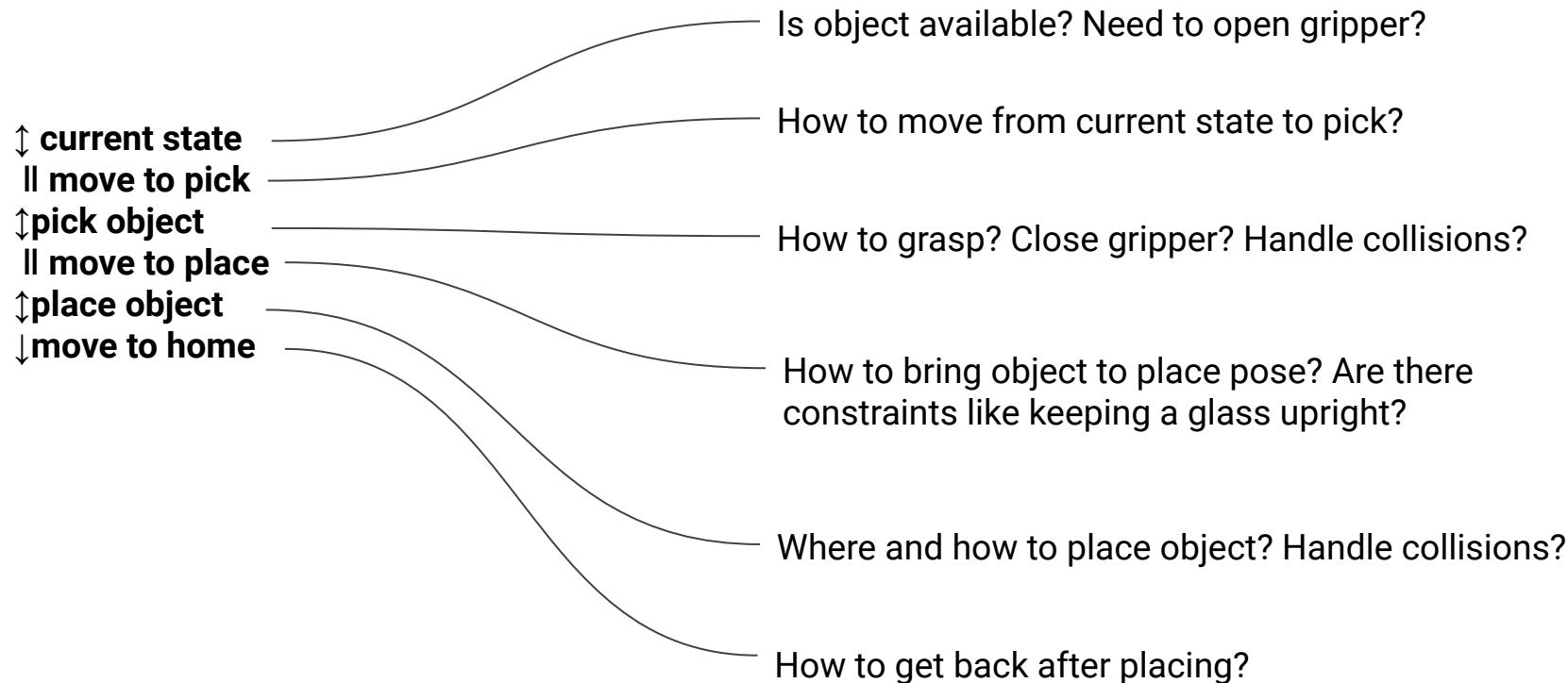
- defines a single motion plan from many subproblems
- solves each subproblem individually
- computes combined start-to-end trajectories
- optimizes with the lowest cost over all subproblems
- “reacting” or “fixing” motions during execution is not supported



https://moveit.github.io/moveit_task_constructor/

99

Multi-step Motion Planning - MTC example

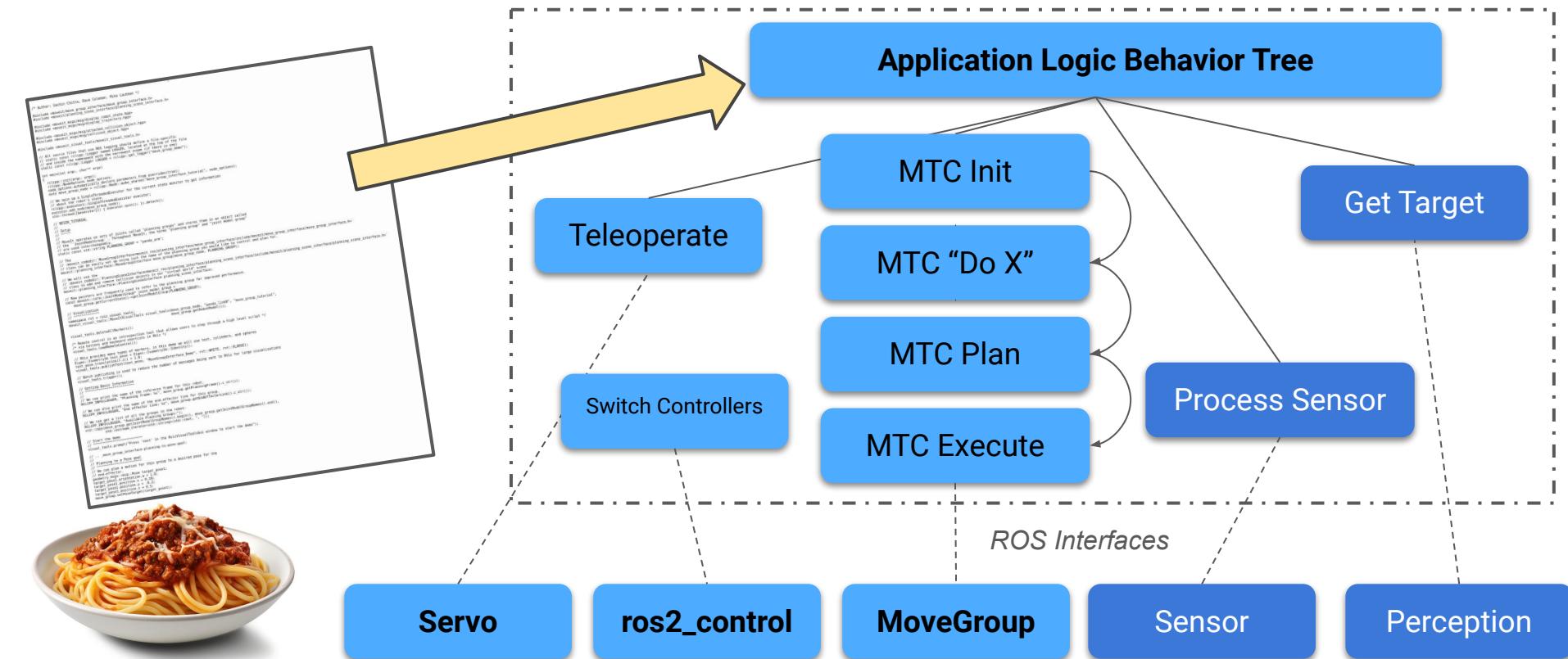


100

https://moveit.github.io/moveit_task_constructor/



Architecture: Spaghetti vs Separation of Concerns



The MoveIt Pro Approach

Behavior Trees

Also known as: Applications, Subtrees

A collection of Behaviors structured as a Behavior tree.
The order of execution is determined by control flow logic
within the tree.

A way to structure the switching between different tasks
in an autonomous agent. An efficient way of creating
complex systems that are both modular and reactive.

Behavior Trees

Behaviors

The smallest building block in MoveIt Pro. Represents a
discrete action like sensing, planning, or executing an
action.

Your Operator Frontend

Your Robot Application Logic

Python or ROS API

MoveIt Pro Runtime

Web UI

Pick & Place

Teleoperation

Your Custom Application

Out of the Box Reference Applications

Behaviors

ML Perception Behaviors

Realtime Control Behaviors

Motion Planning Behaviors

Your Custom Behaviors

The MoveIt Pro Approach

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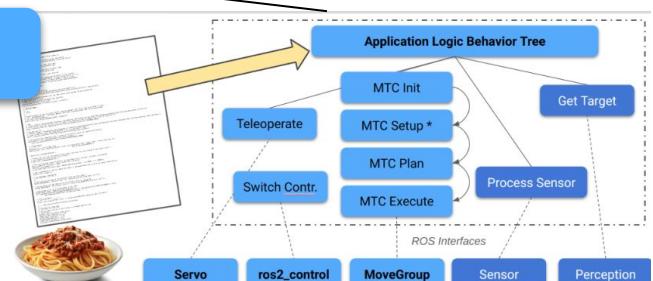
Web UI

Pick & Place

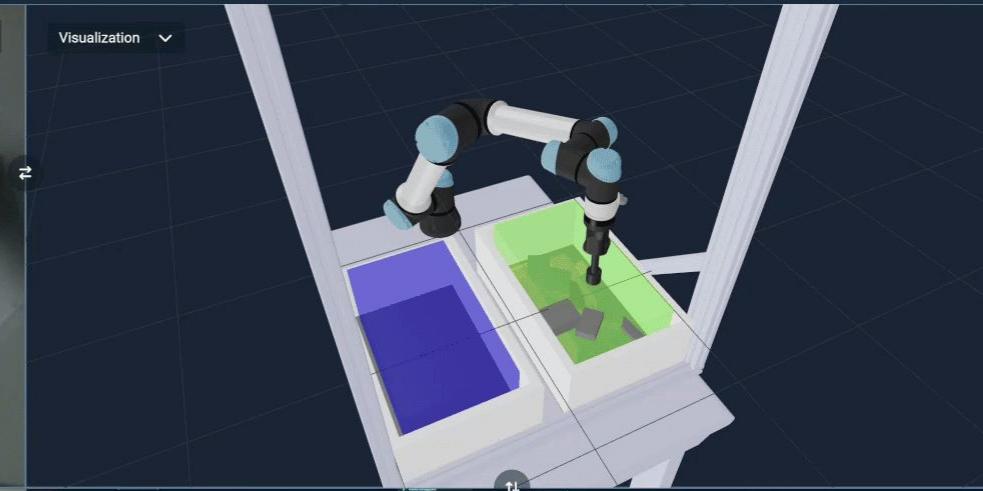
Teleoperation

Out of the Box Reference Applications

Behaviors



Movelt Pro - Bin Picking Application Example



Reminder: Install MoveIt Pro now if you haven't already

- **Follow the install instructions on [Quick Start | MoveIt Pro](#)**
- You should have received an individual **license key** for this workshop via email
- Execute **moveit_pro run** to configure the workspace and build the required images
- If you run into technical difficulties, let us know and we will try our best to fix them
- If you don't have a working installation, please group up with someone who does



Coffee Time!



Exercise 2: External Framework Integration with Pick and Place

Quick Start

An overview of the out of the box functionality

Starting MoveIt Pro

Open a terminal and run:

```
moveit_pro run
```

The first time you run this command, it enters into a “Quick Start” setup mode that will prompt you with a series of setup questions. Choose all the recommended answers:

```
Do you want to download the default workspace now? [Y/n]
Do you want to rebuild the user workspace (recommended)? [Y/n]
Enter the name of the configuration package: arm_on_rail_sim
```

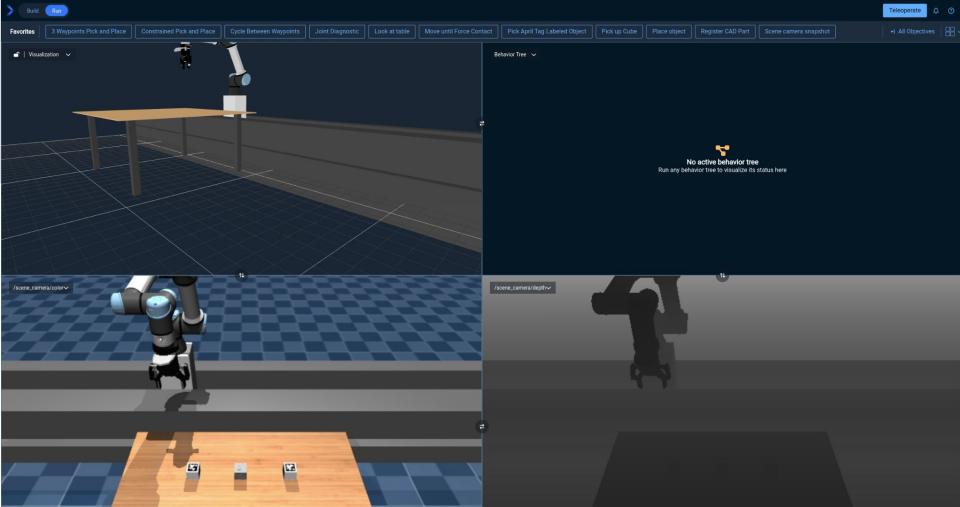
After loading you should see the screen on the right. Ask for help if you run into issues here.

In the future, you can simply launch the same robot config directly via:

```
moveit_pro run
```

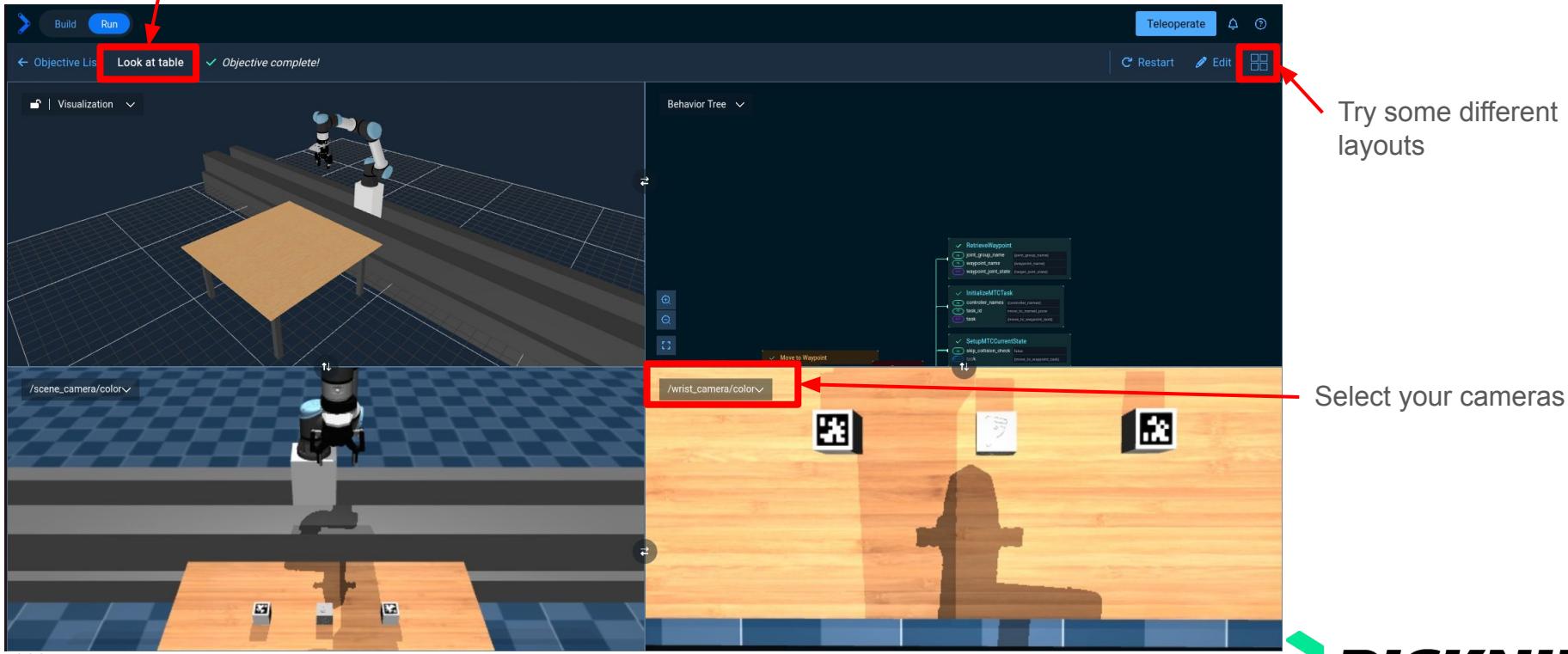
Or more explicitly (in case you have changed robot configs):

```
moveit_pro run -c arm_on_rail_sim
```



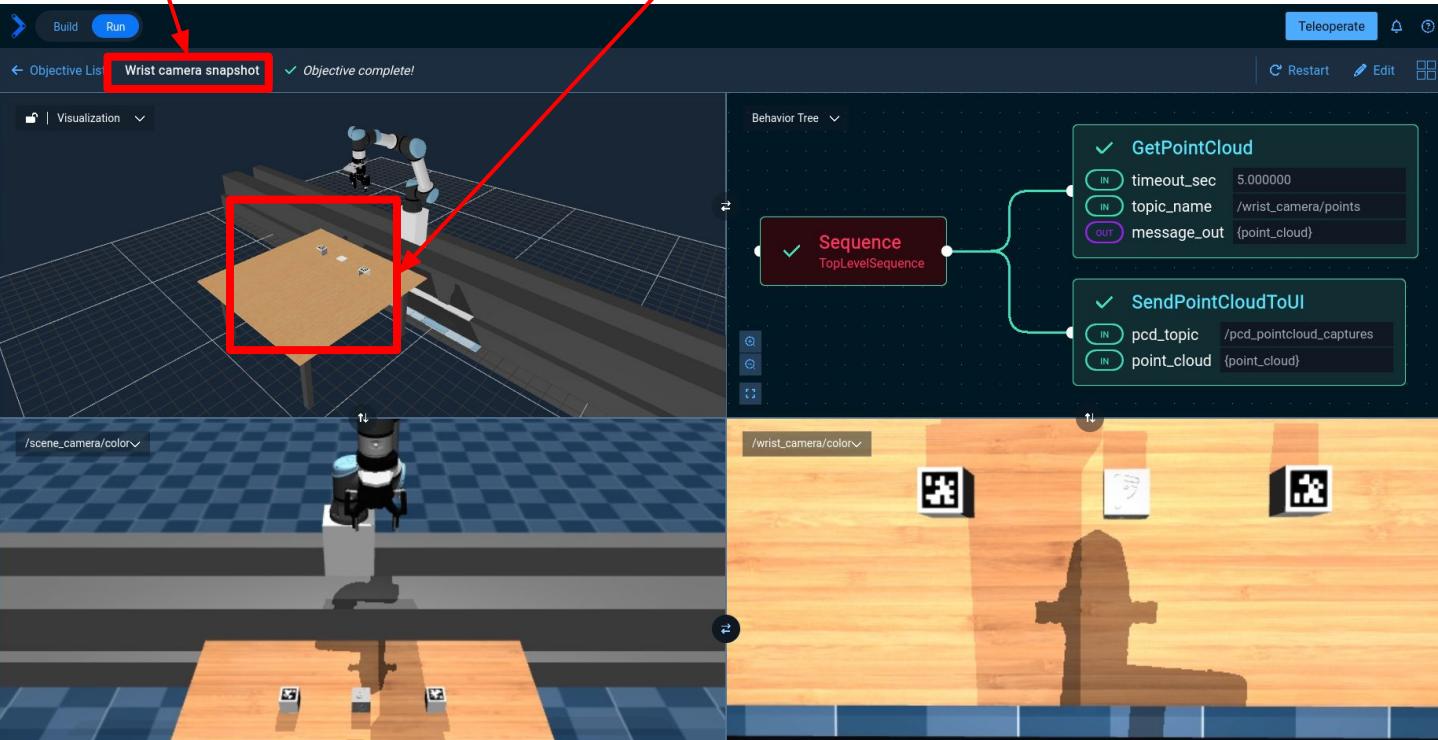
Run your first objective

Run “Look at table” Objective



Use a camera to take a snapshot

Run “Wrist camera snapshot” Objective

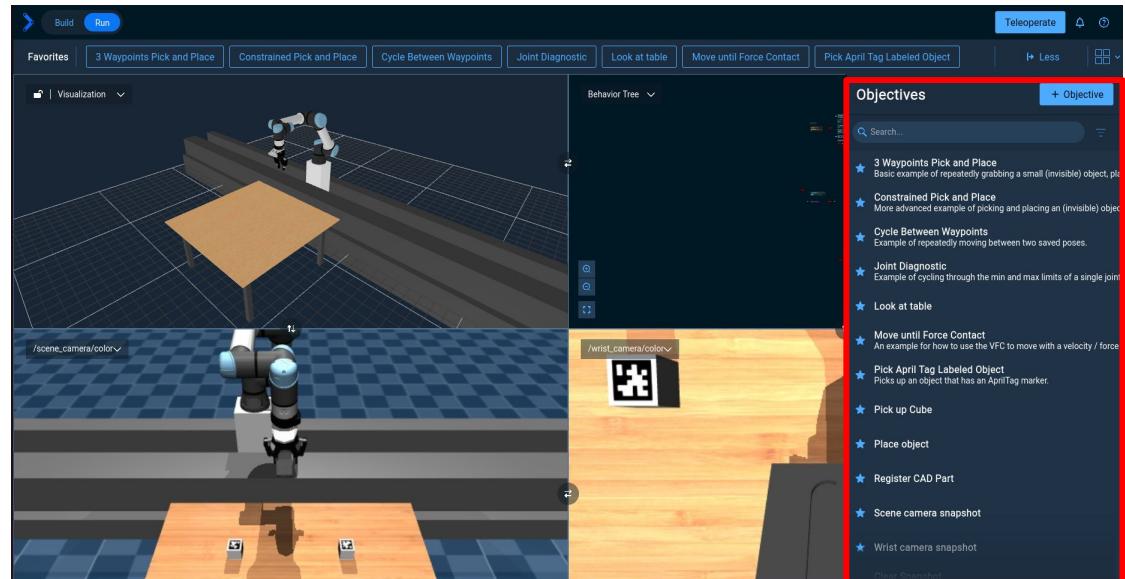


Try out more example Objectives

Before diving in deeper, let's see some more Objectives in action:

Try the following:

- Pick cube
- Place cube
- Open / Close Gripper
- Scene camera snapshot
- Clear snapshot
- 3 Waypoints Pick and Place
 - Use “Stop Motion” button



Cancel/Stop your Objective



- What can we do to get the robot back to a known pose?

Navigating the User Interface

View and execute **Objectives**
(behavior trees that perform a task)

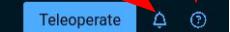


Create and modify behavior trees (**Objectives**) using
a library of **Behaviors** (behavior tree nodes)

You can also write your own custom Behaviors in C++

Control logging
levels

Help and
info

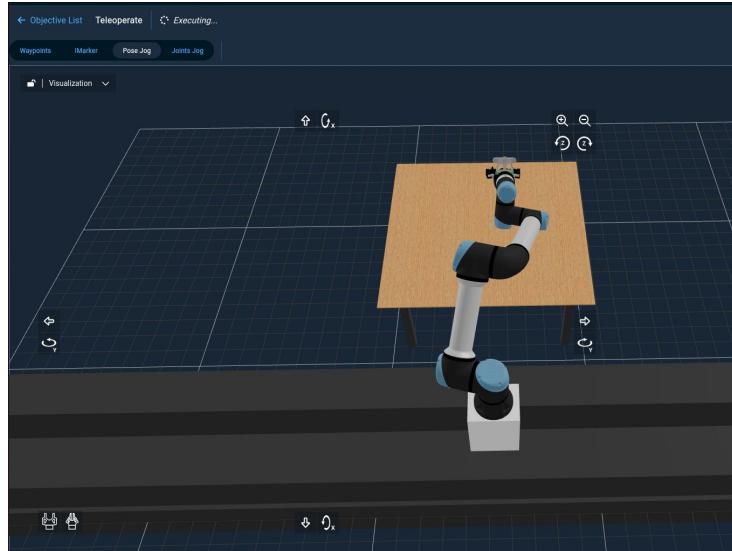


Switch to various manual control
modalities, including:

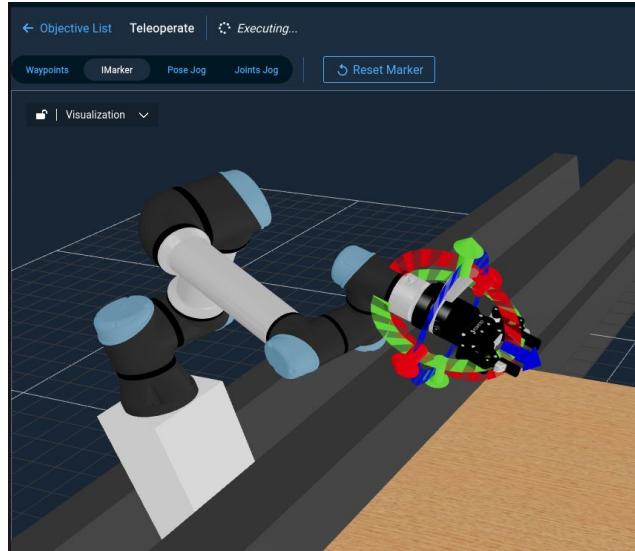
- Cartesian jogging
- Joint jogging
- IMarker control
- Waypoint execution
- Waypoint editing

Teleoperate Screen

Movelt Pro provides several forms of manual control for when a robot needs to be setup, diagnosed, or recovered



Cartesian “Pose Jog”



Interactive Marker



Joint Jog

Saving Waypoints

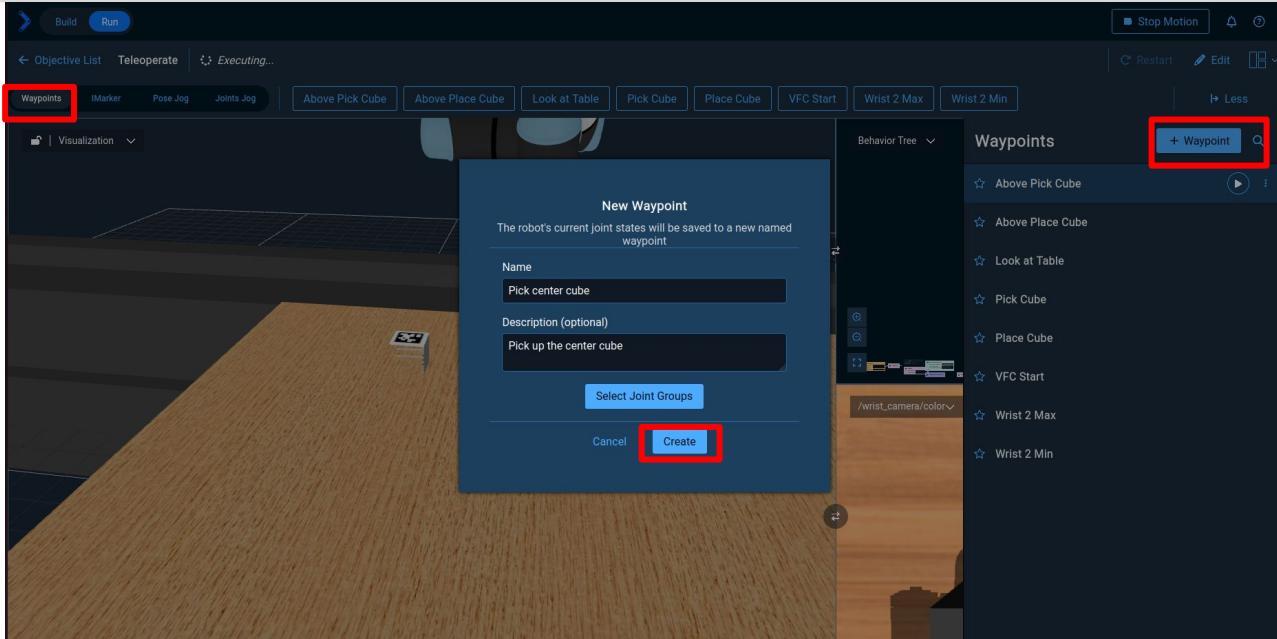
Click **Teleoperate** to control your robot

Select **Waypoints** mode

Click the **All Waypoints** button

Click “**+ Waypoint**” button to save the current pose

We will use these as target joint states for our Objective

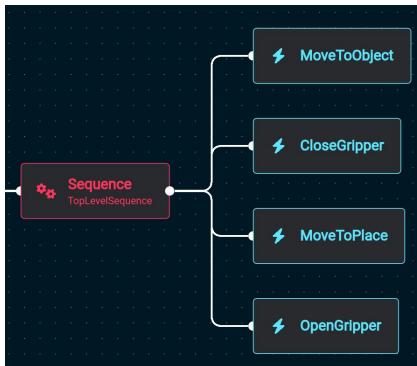


Behavior tree crash course

What is a behavior tree?

Behavior Trees in MoveIt Pro

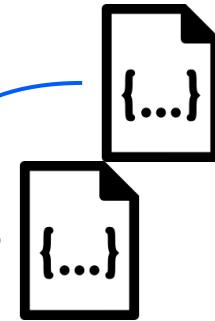
Objectives in MoveIt Pro are implemented as **behavior trees**:



Graphical conceptual model

```
<root BTCPP_format="4">
  <BehaviorTree ID="MainTree">
    <Sequence name="root_sequence">
      <Action ID="MoveToObject"/>
      <Action ID="CloseGripper"/>
      <Action ID="MoveToPlace"/>
      <Action ID="OpenGripper"/>
    </Sequence>
  </BehaviorTree>
</root>
```

XML file



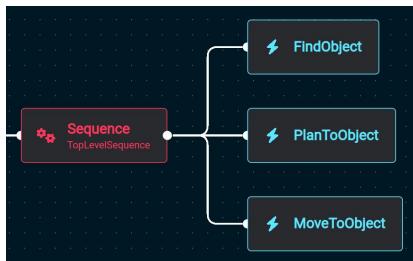
ROS node
implementations

Behavior trees repeatedly **tick** each node, left to right then top to bottom

Behavior Tree Crash Course

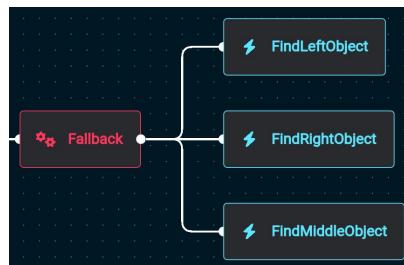
All Behaviors (individual behavior tree nodes) must either:

- Control execution of one or more child nodes
- Contain code that executes at every time step, or **tick**
- Return a **status**: SUCCESS, FAILURE, or RUNNING



Sequence

All nodes must run in order and return **SUCCESS**



Fallback

Try alternatives in order until one of them returns **SUCCESS**

NOTE: There also exist **decorators** to modify the status of a node. Examples:

- Invert (NOT operator)
- Retries / loops
- Delays
- ...



Parallel

Execute all nodes each tick until a terminal state is reached

Data Sharing in Behavior Trees

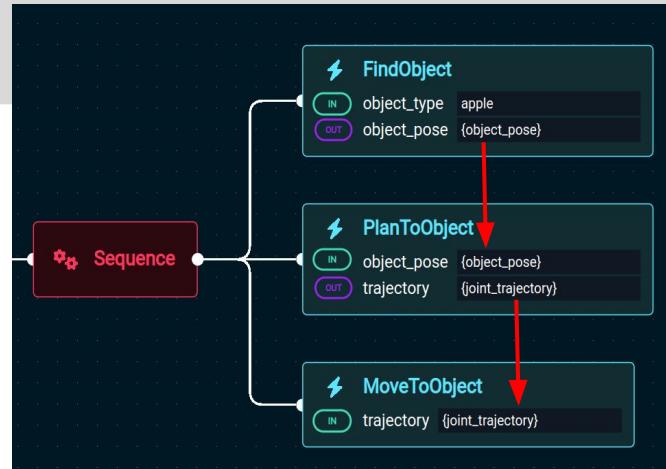
Behaviors communicate with each other via a **Blackboard** (key/value storage).

To manage access to data, Behaviors can assign **ports**.
There are 3 types of ports:

- Input
- Output
- Bidirectional

The blackboard can be used for:

- Passing data as parameters between behaviors
- Updating state (e.g, counters, queues, lists)



KEY	TYPE	VALUE
<code>object_type</code>	string	<code>apple</code>
<code>object_pose</code>	Pose	<code>{object_pose}</code>
<code>trajectory</code>	Trajectory	<code>{joint_trajectory}</code>

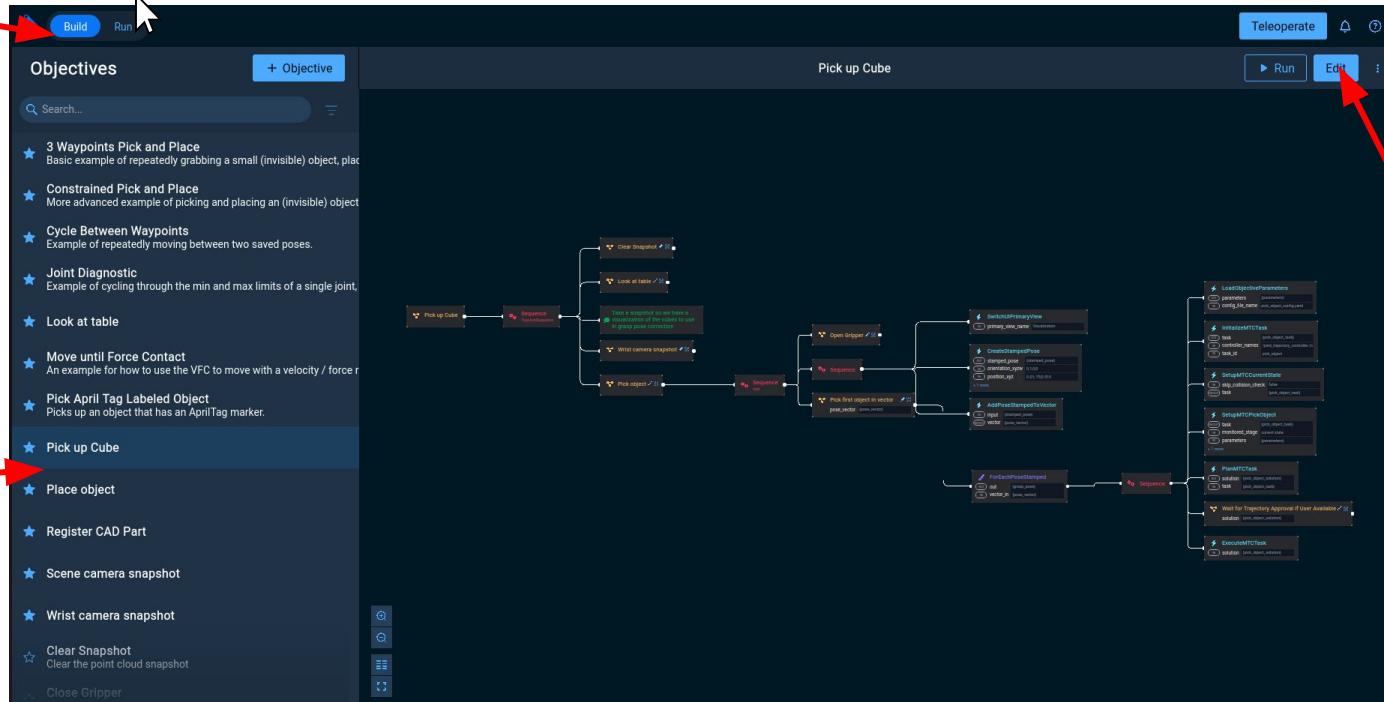
Note: {brackets} = value set by a Behavior

Modify your first Objective

How to customize an existing application

Edit the Pick up Cube Objective

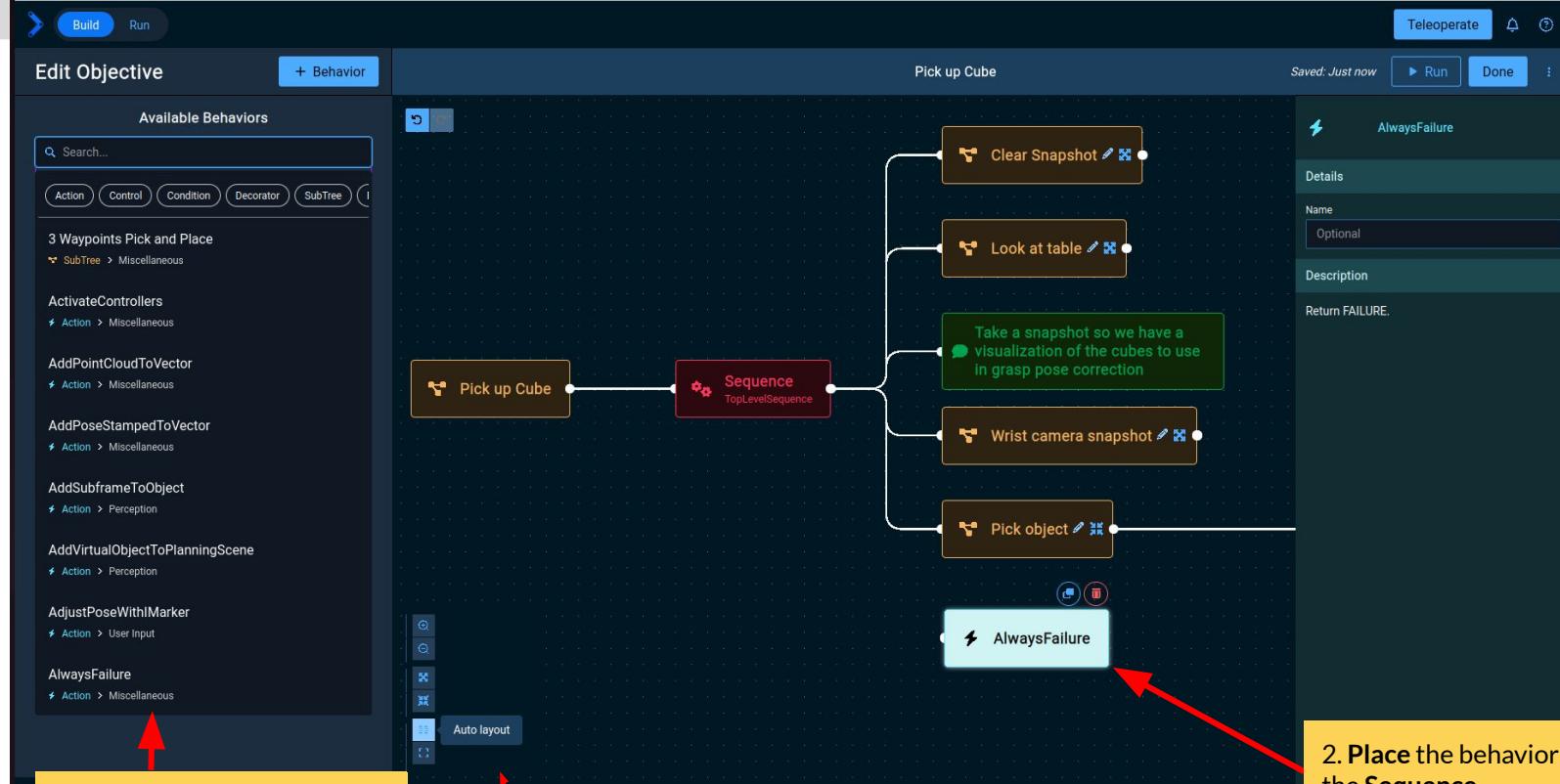
1. Select Build



3. Edit the objective to start customizing it

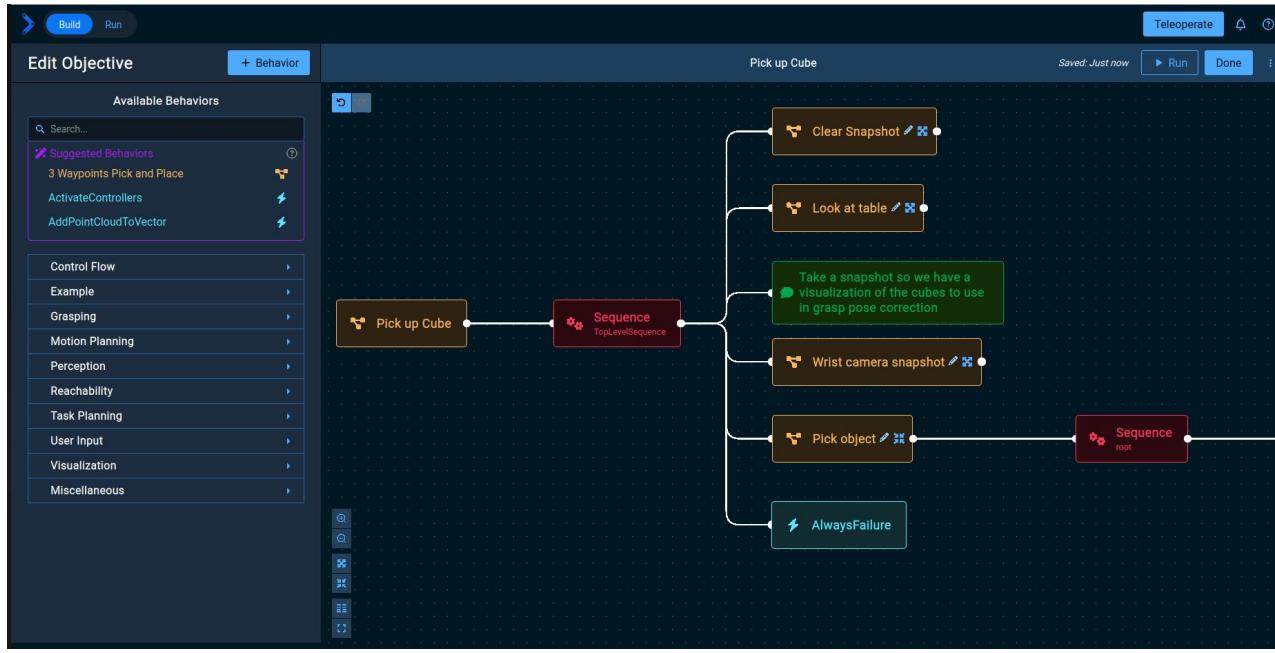
2. Choose Pick up Cube

Create a Failure Scenario



Discussion

- What happens when we run the objective?
- What can we do to recover from failures?

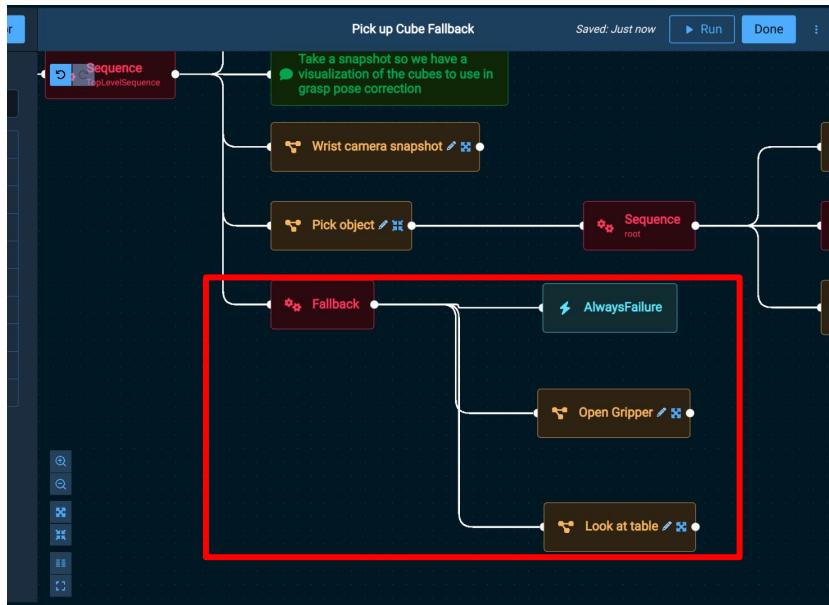


Add Error Recovery to an Objective

How to build failure recovery into your behavior tree

Add a fallback node

1. Edit “Pick up Cube”
2. Click the “AlwaysFailure” behavior input connection in the BTree
3. Highlight the input connection then [Delete] to disconnect
4. Drag in a “Fallback” control node
 - a. From the list of available Behaviors on the left panel
 - b. Controls -> Miscellaneous -> Fallback
5. Use the white connection points (dots) to connect nodes
6. Add a recovery behavior
 - a. Use **Open Gripper** to clear the end effector
 - b. Run **Look at Table** to bring the robot to a well-defined state



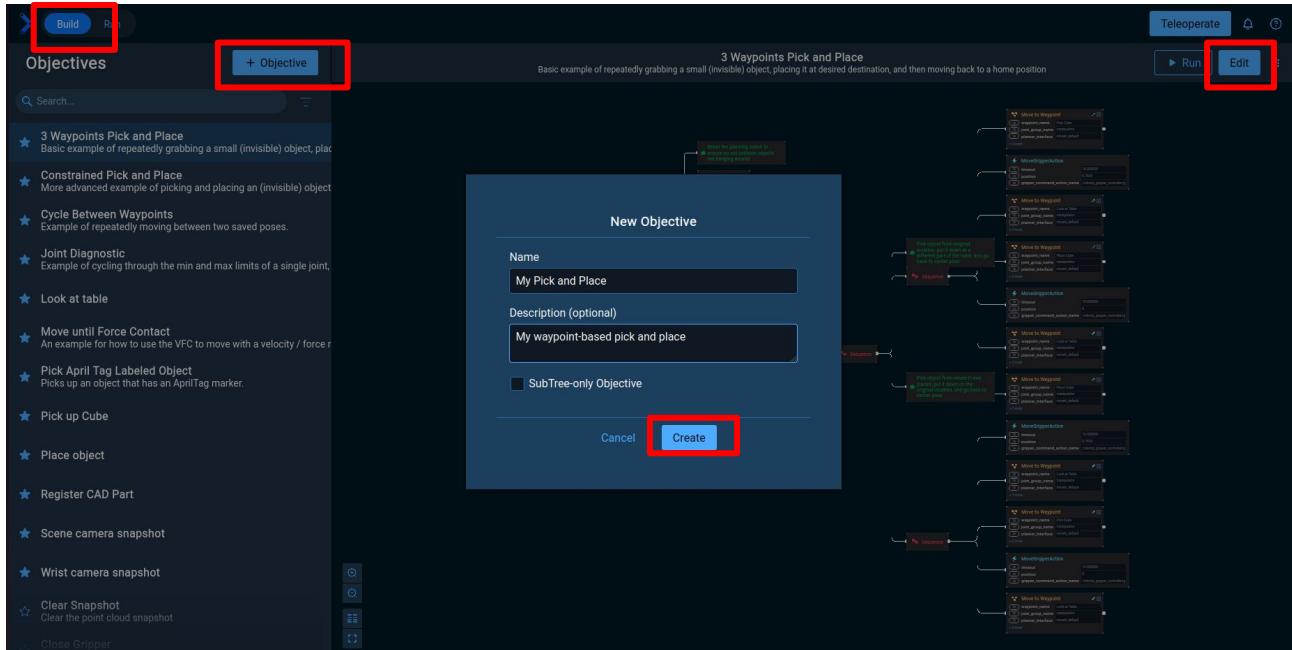
What happens when you run now?

Create an Objective from Scratch

Without modifying an existing Objective

Creating a New Objective

1. Use the **Build** tab to create a new Objective.
2. Name it: **My Pick and Place**
3. Select **Edit** and start adding Behaviors from the list on the left side.
4. Build and test incrementally!

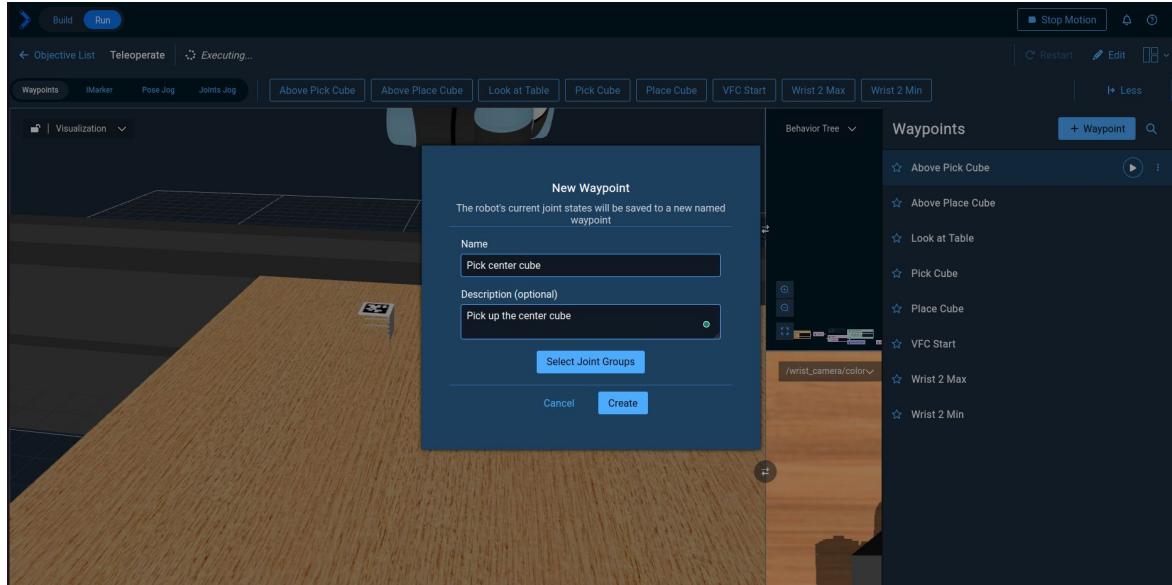


Build a Waypoint-Based Pick and Place Application

Example:

1. Look at Table
2. Take snapshot
3. Open gripper
4. Move to pick pose
5. Close gripper
6. Move away from the object
7. Move to a placement pose
8. Open gripper

Can we use **Waypoints** and built-in **Behaviors** to make an **Objective**?



Summary and Conclusion

What have we discussed?

- What are motion planning and MoveIt, and what you can do with them
- What are some planners available in MoveIt and what goes into motion planning?
- MoveIt concepts and configurations
- How to use MoveGroup to generate motion plans
- What is manipulation, and how that is different from motion planning
- What you need to solve a manipulation problem in production
- How to use frameworks, tools, and libraries on top of MoveIt to structure your manipulation tasks

Takeaways

- Movelt is a motion planning framework
 - Generate motion plans using MoveGroup or MoveltCpp
- Manipulation tasks involve more than just motion planning
- Tools built on top of Movelt's motion planning capabilities can help solve manipulation tasks reliably
 - [Movelt Task Constructor](#) is an open-source tool to build a manipulation task that consists of a series of connected motion plans
 - [BehaviorTree.CPP](#) is an open-source behaviour tree implementation that can be used to control execution of a manipulation task (perception failures, planning failures, driver errors, etc.)
- [Movelt Pro](#) builds upon Movelt motion planning, Movelt Task Constructor, behavior trees, perception, pre-built implementations of common manipulation steps, and more.

Resources

- **MoveIt 2**
 - Website: <https://moveit.ai>
 - Repository: <https://github.com/moveit/moveit2>
- **MoveIt Task Constructor:** https://github.com/moveit/moveit_task_constructor
 - MoveIt Maintainer Team, Robert Haschke and Michael Görner in particular
- **Behavior Tree.CPP:** <https://www.behaviortree.dev/>
 - Davide Faconti (he's here at ROSCon 2024, feel free to ask him about behavior trees)
- **MoveIt Pro:** <https://picknik.ai/pro/>
 - Docs: <https://docs.picknik.ai/>
 - Contact: <https://picknik.ai/connect/>



Join our Happy Hour for drinks and chats!



When? Today, October 21st at 5PM

Where? Anarkist Beer & Food Lab, Albanigade 20 (10 min walk)

sponsored by



Q&A

Raise your hand or ask on Slido:

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