PICKNIK

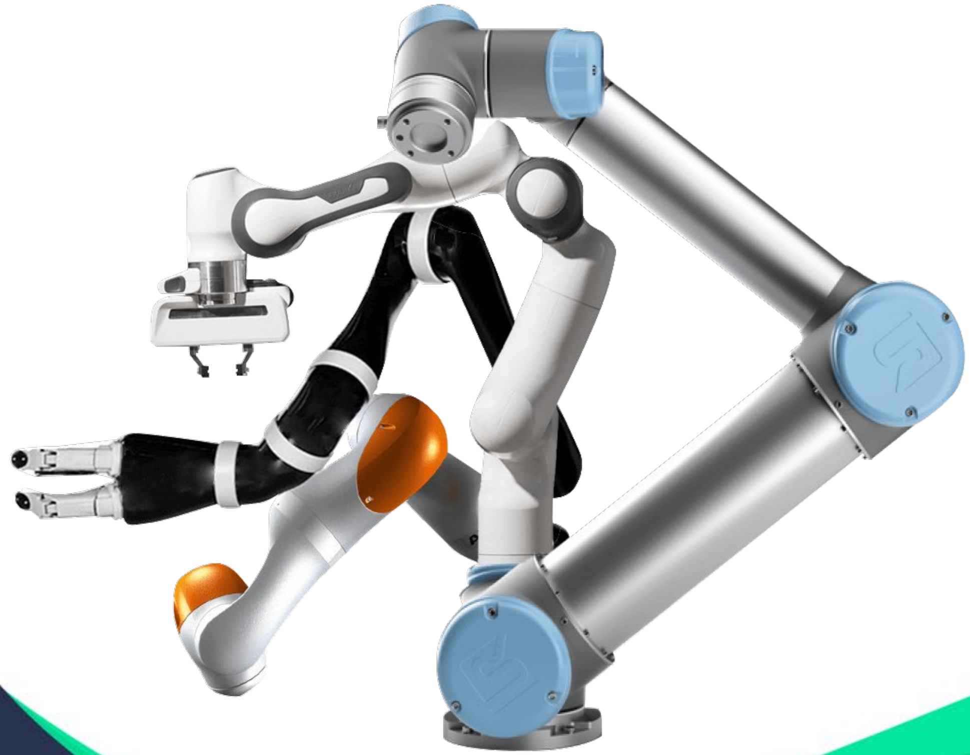
MoveIt

Optimizing MoveIt

Costs, Constraints and Betterments

October 19, 2023

Lars Henning Kayser
MoveIt Chief Architect
henningkayser@picknik.ai



Quick facts

about me

- **2018**
  - M.Sc. CS at University of Hamburg, TAMS robotics lab
  - Hired by PickNik after introduction at ROSCon Madrid
- **Since then**
  - 20+ clients, leading 6 projects
    - industrial, medical, construction, agriculture, logistics, …
    - primarily consulting and R&D, motion planning - MoveIt, C++
  - MoveIt ROS 2 migration, ROSin project (EU Horizon 2020)
- Now: MoveIt Chief Architect (or Archeologist?)
  - OSS Maintenance, internal R&D, TSC member

Optimizing MoveIt

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01 **Inverse Kinematics**
Solving / Sampling / Optimizing

02 **Motion Planning**
Searching / Optimizing / Ranking

03 **Miscellaneous**
Projects / Python / Parameters / PRs

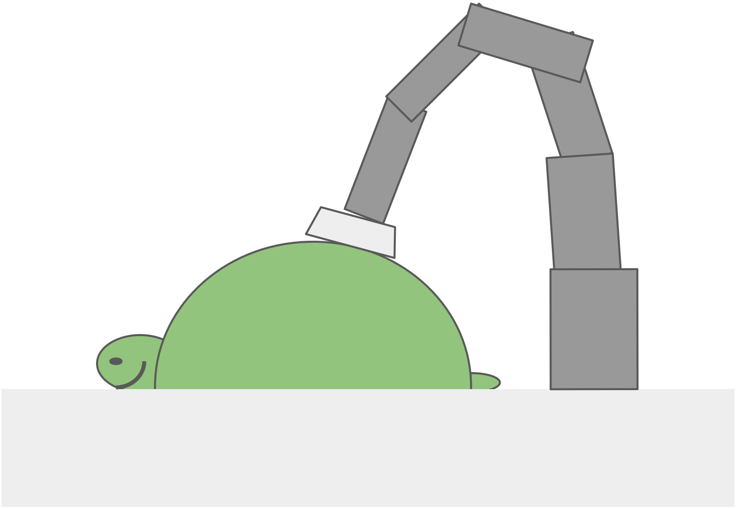
Inverse Kinematics

Solving / Sampling / Optimizing

IK - Problem

Example: Turtle Cleaning Robot

repo: https://github.com/henningkayser/roscon23_moveit



Problem: Find initial robot state to gently apply scrubber!

IK - Solvers

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Solver Plugins

IKFast
repo: MoveIt

KDL
repo: MoveIt

trac_ik
repo: https://bitbucket.org/traclabs/trac_ik/src/rolling-devel/

bio_ik
repo: https://github.com/TAMS-Group/bio_ik
ros2: https://github.com/PickNikRobotics/bio_ik/tree/ros2

pick_ik
repo: https://github.com/PickNikRobotics/pick_ik

Configuration: kinematics.yaml

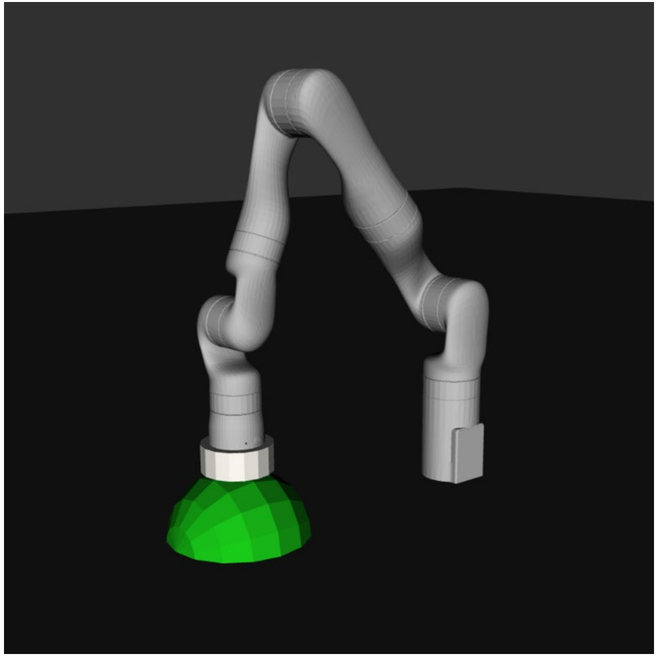
```
manipulator:
  kinematics_solver: kdl_kinematics_plugin/KDLKinematicsPlugin
  …
```

C++ Implementation

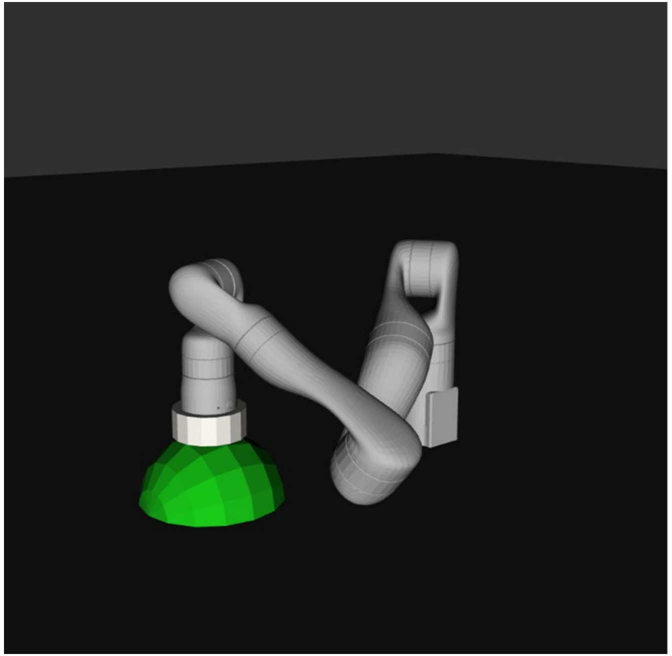
```
// … initialize:
//         RobotState target_state
//         JointModelGroup arm_group
//         PoseStamped turtle_pose

PoseStamped target_pose = turtle_pose;
target_pose.pose.position.z += turtle_radius;

target_state.setFromIK(arm_group, target_pose);
```

IK - Solution

Very often



Sometimes



IK - Limitations

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We don’t always want or need fully constrained target poses

- **Tools can often be applied with some tolerance**
  - Suction grippers, laser scanning, spin scrubbers …
- **We may compromise orientation accuracy for position accuracy**
  - Laser cutting, welding, assembly
- **Unstructured robot environments may require**
  - Additional safety margins, collision clearance
- **Reachability issues may lead to**
  - joint flips, high failure rate, solutions near singularities or joint limits

We can increase the solution space using problem-specific constraints!

IK - Constraints

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Constraints are rules that decide the binary validity of a state

- Implementation types
  - Threshold functions with target value and tolerance range
  - Bool functions that perform on non-gradient metrics

- MoveIt supports
  - **Position, Orientation, Joint, Visibility** constraints
  - Collisions, joint limits are implicitly constraining solutions

IK - Position Constraint

We can model the space of valid poses as single position constraint!

PositionConstraint (moveit_msgs)

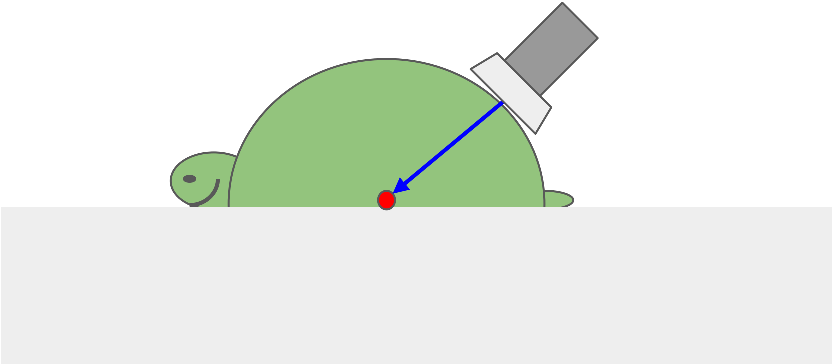
std_msgs/Header header ← **turtle pose frame**

string link_name ← **IK link**

geometry_msgs/Vector3 target_point_offset ← **IK frame offset**, turtle radius along Z-axis

moveit_msgs/BoundingVolume constraint_region ← **tiny primitive shape**, sphere at center of turtle

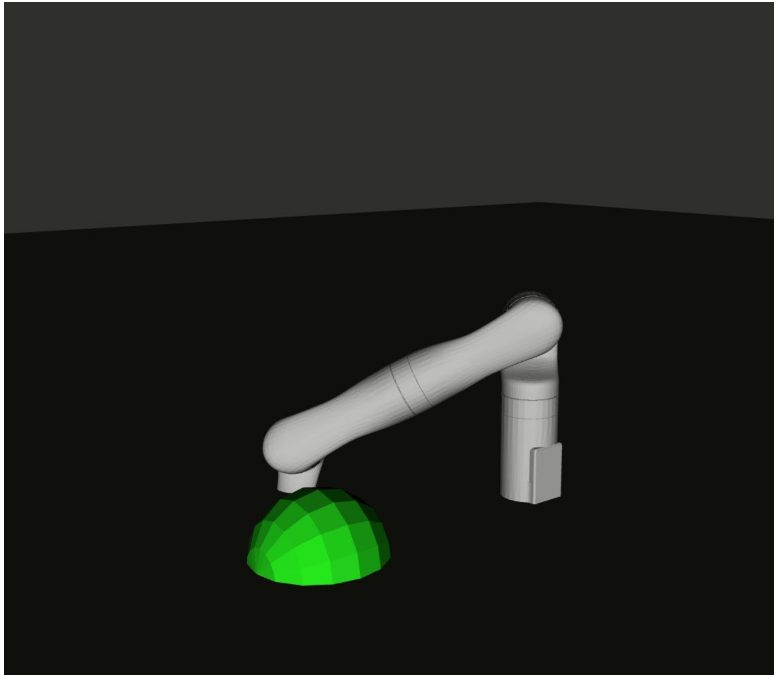
float64 weight (unused for now)



IK - Constraint Sampler

```
#include <moveit/constraint_samplers/constraint_sampler_manager.h>
#include <moveit/kinematic_constraints/utils.h>

// … init std::string link_name, PlanningScene scene

geometry_msgs::msg::PointStamped target_point;
target_point.header = turtle_pose.header;
target_point.point = turtle_pose.pose.position;

geometry_msgs::msg::Point link_offset;
link_offset.z = turtle_radius;

using kc = kinematic_constraints;
auto constraints = kc::constructGoalConstraints(link_name, link_offset, target_point);

constraint_samplers::ConstraintSamplerManager sampler_manager;
auto goal_sampler =
  sampler_manager.selectSampler(scene, arm_group->getName(), constraints);

goal_sampler->sample(target_state);
```

IK - Constraint Sampler



Obviously, collision checks are not enabled here.
We either have to reject a lot of samples (costly!) or add additional constraints.

IK - Solution Quality

What if we want quality criteria like …

1. **reducing the joint distance from the current configuration**

1. **repeatable or at least similar solutions**

1. **preference for contact points near an ideal target**

… and all that at the same time?

IK - pick_ik

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Plugin Implementation

- Thread-safe reimplementation of bio_ik
- Provides gradient descent (local) and memetic (global) optimization
- Built-in cost objectives
  - minimal displacement
  - center joints
  - avoid joint limits
- Supports dynamic parameter updates

Configuration: kinematics.yaml

```yaml
manipulator:
  kinematics_solver: pick_ik/PickIkPlugin
  mode: global  # global, local
  position_scale: 1.0  # factor for position distance cost
  rotation_scale: 0.5  # factor for rotation distance cost
  position_threshold: 0.005  # max allowed position cost
  orientation_threshold: 0.01  # max allowed orientation cost
  minimal_displacement_weight: 0.0 # minimize seed distance
  center_joints_weight: 0.0 # keep joint values centered
  avoid_joint_limits_weight: 0.0 # penalize states near limits
```

… and implements MoveIt’s new IK Cost function API!

IK - Cost Function API

Inject quality metrics into IK solver plugins

- IK callback for computing cost values for solver-internal samples
- Currently, only supported by pick_ik, bio_ik (ros2 PickNik fork)

```
// moveit_core/kinematics_base/…/kinematics_base.h, class KinematicsBase

using IKCostFn = std::function<double(const geometry_msgs::msg::Pose& target_pose,
                                      const moveit::core::RobotState& sample_state,
                                      const moveit::core::JointModelGroup* group,
                                      const std::vector<double>& seed_positions)>;
```

IK - Constraint -> Cost Function

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```
// …

kc::KinematicConstraintSet constraints_validator(robot_model);
constraints_validator.add(constraints, scene->getTransforms());

auto constraints_cost_fn = [&](const geometry_msgs::msg::Pose& /* target_pose */,
                               const RobotState& sample_state,
                               const JointModelGroup* /* group */,
                               const std::vector<double>& /* seed_positions */)
{
  return constraints_validator.decide(sample_state).distance;
};

target_state.setFromIK(arm_group,
                       target_pose,
                       0.05,  /* seconds timeout */
                       GroupStateValidityCallback(),
                       KinematicsQueryOptions(),
                       constraints_cost_fn);
```

IK - Constraint -> Cost Function

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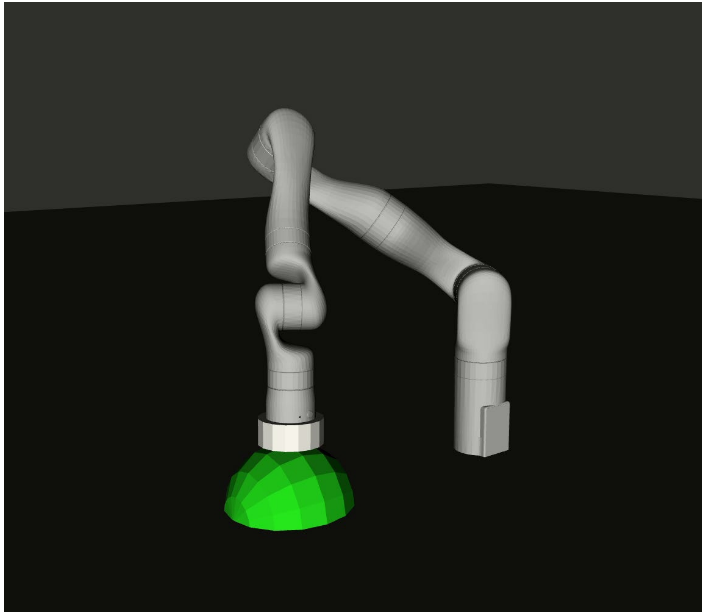
- We still pass the initial target pose to the IK call
- Setting **return_approximate_solution** to **true** allows diverging from it
- pick_ik provides additional *approximate_** parameters for tuning cost thresholds

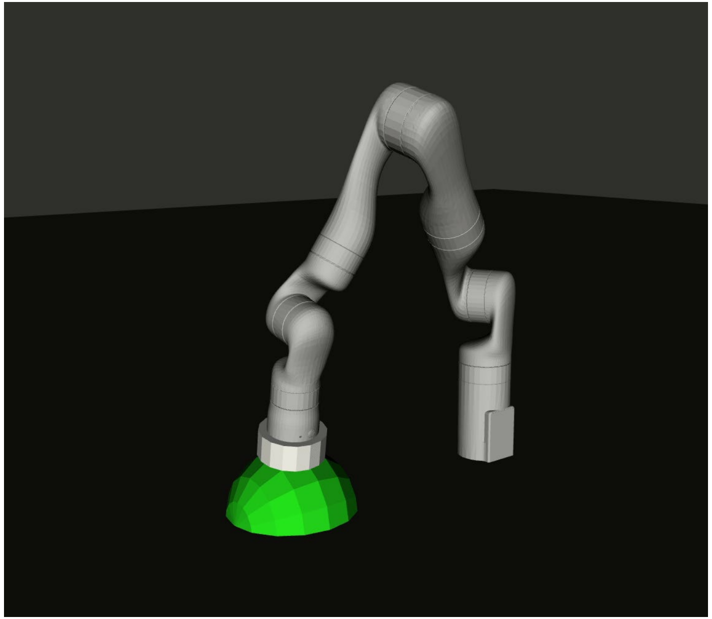
```
// …


auto ik_options = kinematics::KinematicsQueryOptions();
ik_options.return_approximate_solution = true;

target_state.setFromIK(arm_group,
                       target_pose,
                       0.05,  /* seconds timeout */
                       GroupStateValidityCallback(),
                       ik_options,
                       constraints_cost_fn);
```

IK - pick_ik Solutions

Same start state (20 solutions)



Random start state (20 solutions)



Optimization-based IK

Advanced Use Cases

- Cartesian Interpolation

  MoveIt's Cartesian Interpolator supports IK cost functions!

- Visual Servoing

  "local" modes are feasible for computing controller waypoints online (requires post-processing)

- Collision Clearance

  A collision distance check as cost function allows "pushing" the robot away from obstacles

Optimization-based IK

Limitations

- Conflicting Cost Terms

  “Too many cooks…” - already position and orientation targets may conflict, produce offsets

- Performance

  cost functions need to be very efficient, otherwise solver time explodes

- Weighting

  Cost terms are balanced by weight. Tuning them may come close to “magic numbers”

IK - Take Aways

Fully constrained IK can have undesired side effects

- restricts solution space too much
- can produce reachability issues, joint flips
- “bad” IK solutions can cause path sampling and motion planning issues

Constraints define some IK problems more elegantly

- increase the solution space
- enable trade offs between solution accuracy and quality criteria
- IK constraints can be sampled and filtered

Cost Functions allow optimizing quality metrics

- cost functions can be derived from constraints with distance metrics
- IK Solvers can optimize for multiple weighted cost functions at the same time
- Optimization can be global or local, depending on the problem

Motion Planning

Searching / Optimizing / Ranking

Planning with Constraints (OMPL)

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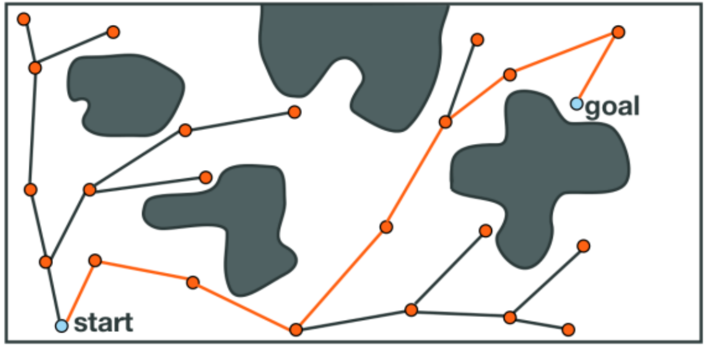
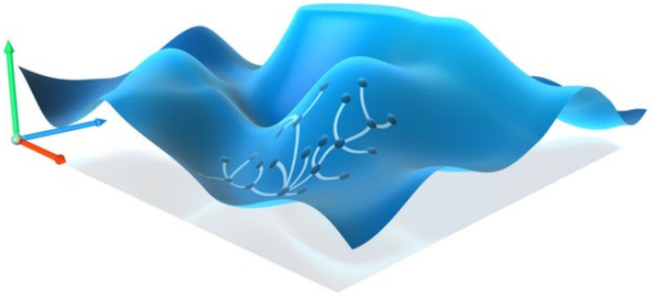
… is very difficult!

- OMPL used to sample states in **joint space** or **Cartesian space**
  - joint samples require validation = Rejection Sampling
  - Cartesian samples require IK
- Interpolated states need to be validated as well
- Best approach so far was using a search space (= constraint manifold) approximation
  - pre-computed database with valid states
  - Sucan et al, IROS **2012!**





Planning with Constraints (OMPL)

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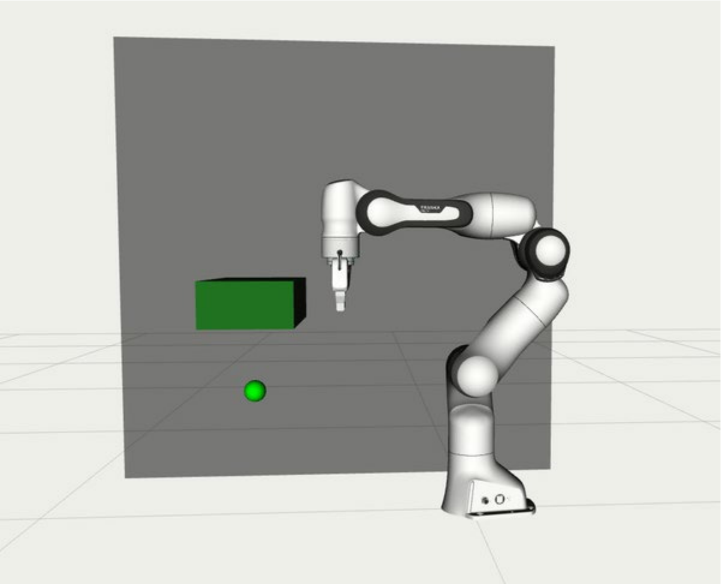
OMPL Constrained Planning

- New adapters to OMPL's constrained planning framework (Kingston, 2019)
- Projects sampled states into the constraint manifold using error Jacobian
  - optimization on constraint derivative gradient
- Supports any OMPL planning algorithm
- Implemented for **Position** (BOX), **Orientation**, and **Equality**

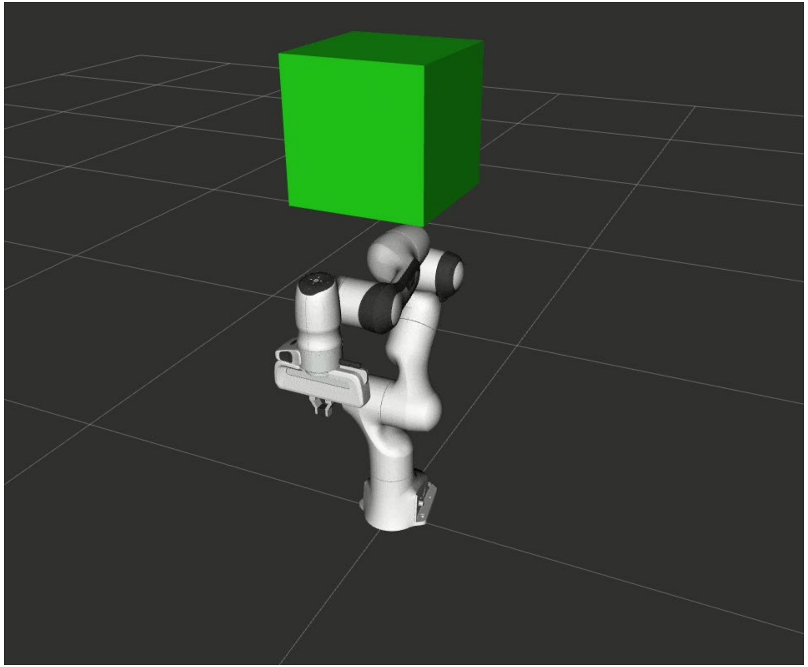


Tutorial https://moveit.picknik.ai/main/doc/how_to_guides/using_ompl_constrained_planning/ompl_constrained_planning.html

STOMP

Stochastic Trajectory Optimization for Motion Planning

- Finds smooth collision free paths using probabilistic optimization
- Starts with an initial (maybe infeasible) guess
- The initial path is iteratively optimized by minimizing individual waypoint costs over randomized samples
- Advantages:
  - Cost function does not need to be differentiable
  - Can incorporate additional cost terms



STOMP

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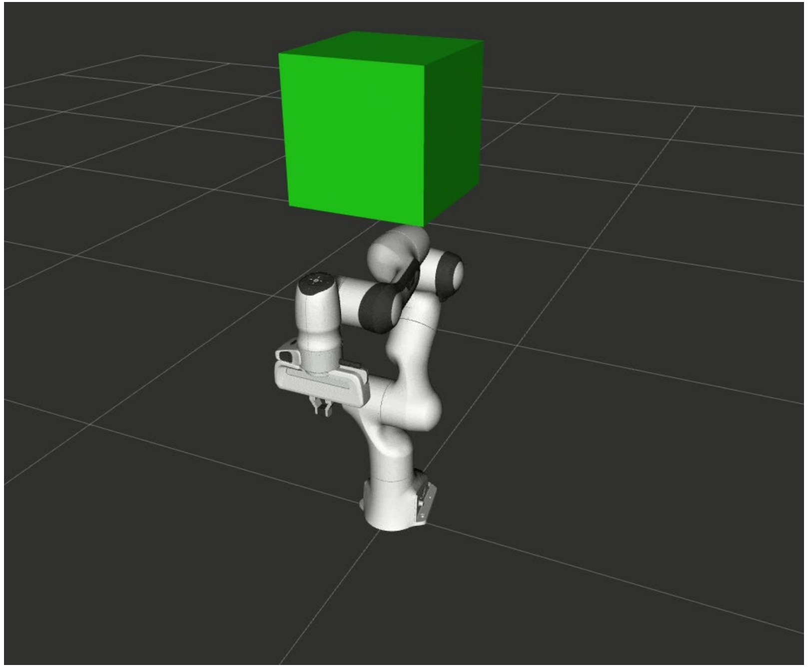

Complete reimplementation!

- C++ callbacks instead of plugins
    - noise, costs, filter, post conditions
    - supports arbitrary constraints
        - caveat: probably more useful for post processing OMPL if problem is challenging
- **NOTE: cost function API similar to CostIKFn() is WIP!**

Tutorial https://moveit.picknik.ai/main/doc/how_to_guides/stomp_planner/stomp_planner.html

Parallel Planning

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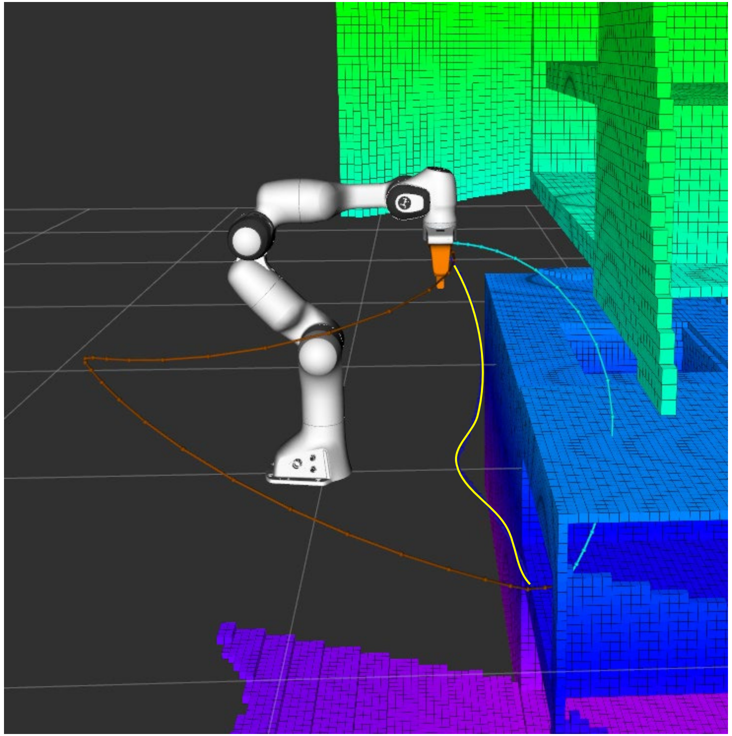
Solution quality depends on the planning algorithm

-> Picking the best algorithm for a given problem is not intuitive

Even the “best” algorithm can fail

-> In this case we need a fallback planner



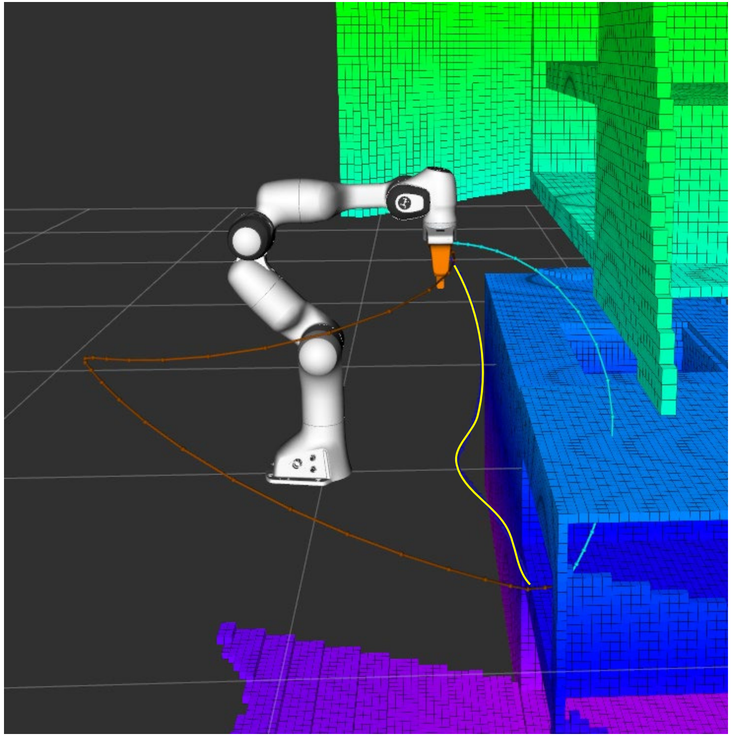
Approach

Run a **Portfolio of Planners** in parallel and pick the best!

Parallel Planning

Semi-autonomous choice of the most suitable planner for a given problem

- Customizable stopping criteria
- Customizable solution selection
- Good default but no “real” optimization



Miscellaneous

Projects / Python / Parameters / PRs

Major Contributions

GSoC: Python Bindings
Peter David Fagan

GSoC: IK Benchmarking
Mohamed Raessa & Sebastian Castro

GSoC: Servo Refactor
Mohammed Ibrahim & Sebastian Castro

Iron Release
Henning Kayser

Isaac Integration
Marq Rasmussen & Jafar Abdi

Unifying Parameter Approach
Tyler Weaver

Parameters

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generate_parameters_library

- declarative, validatable and (almost) self-documenting ROS 2 parameters
- repo: https://github.com/PickNikRobotics/generate_parameter_library

Visit Tyler Weaver's talk "Parameters should be boring"!

tomorrow, 2:10 PM CST, "ROS Development" track

Python Bindings

moveit_py

2022 GSoC - **Peter David Fagan**

- Python bindings to **MoveItCpp** and **moveit_core** classes
- Goal: facilitate integrating and prototyping with other Python libraries

Google Summer of Code

Tutorial

https://moveit.picknik.ai/main/doc/examples/motion_planning_python_api/motion_planning_python_api_tutorial.html

```
rclpy.init()
logger = rclpy.logging.get_logger("moveit_py”)

# instantiate MoveItPy instance and get planning component
robot = MoveItPy(node_name="moveit_py")
robot_arm = robot.get_planning_component("arm")
logger.info("MoveItPy instance created")

# set plan start and goal states using predefined states
robot_arm.set_start_state(configuration_name="ready")
robot_arm.set_goal_state(configuration_name="extended")

# plan to goal
arm_motion = robot_arm.plan()

# execute trajectory
if (arm_motion):
    robot.execute(arm_motion.trajectory)
```

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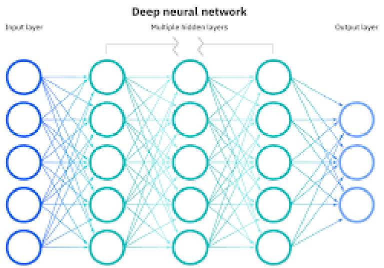
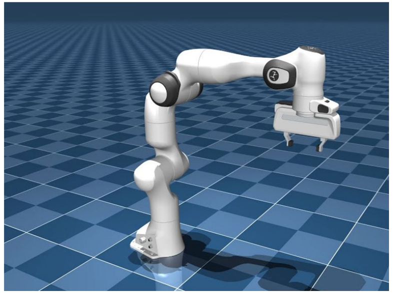
Advanced Use Cases

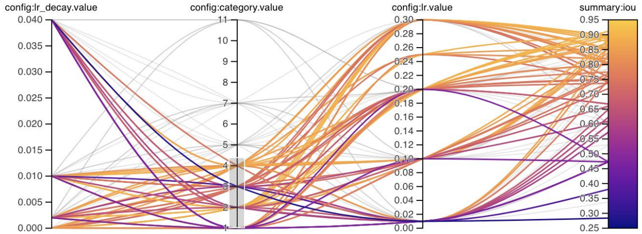
Learning



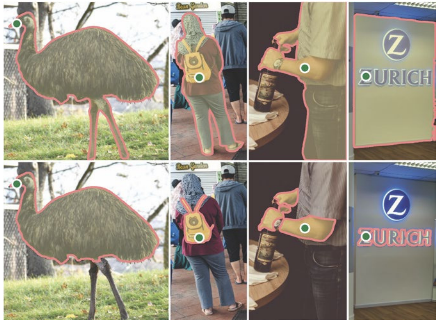
Simulation



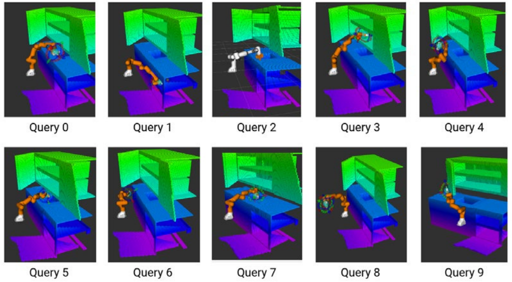
Parameter Tuning



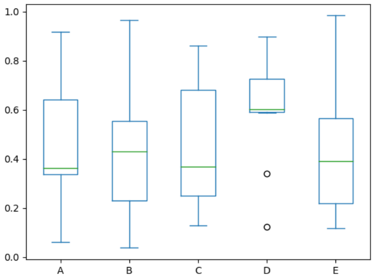
Perception



Benchmarking



Data Visualization



Future Work? Community!

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Grow Community - We want YOU to start playing with this!

What use cases are you interested in?

Which Python library would you like to integrate?

What interfaces do you need for that?

PyTorch

DRAKE

pandas

Pinocchio

Efficient and versatile rigid body dynamics algorithms

MuJoCo

MoveIt Project Planning

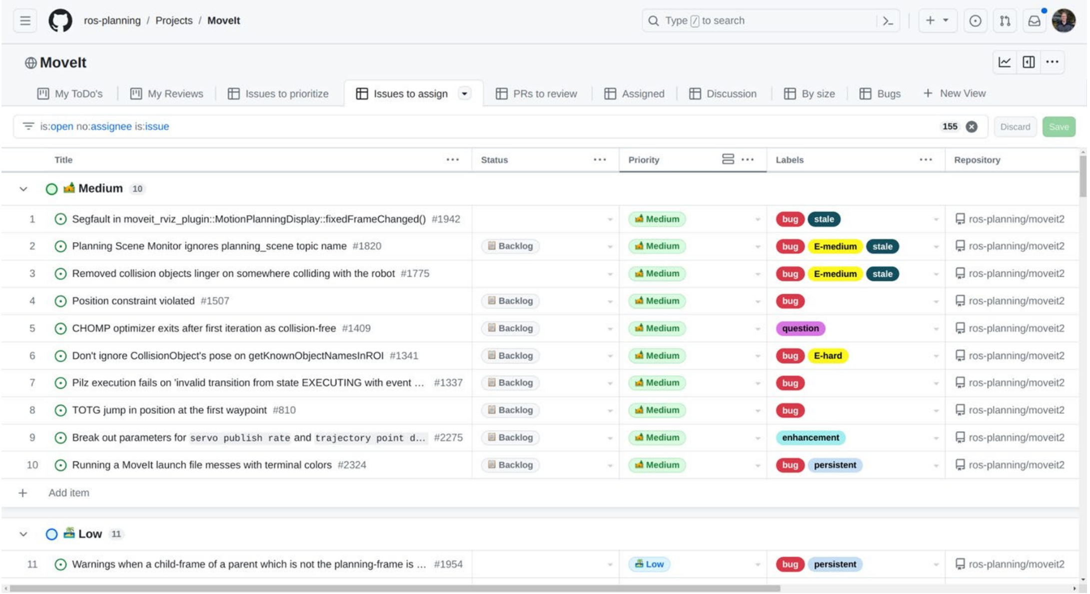
Weekly Developer Standup

Tuesdays, 8:30AM Mountain Time

Monthly Working Group / MoveIt Maintainer Meeting

4th Thursday, 9AM Mountain Time

ROS Discourse



ros-planning / Projects / MoveIt

Type / to search

MoveIt

My ToDo's | My Reviews | Issues to prioritize | Issues to assign | PRs to review | Assigned | Discussion | By size | Bugs | + New View

is:open no:assignee is:issue 155 Discard Save

	Title	Status	Priority	Labels	Repository
	Medium 10				
1	Segfault in moveit_rviz_plugin::MotionPlanningDisplay::fixedFrameChanged() #1942		Medium	bug, stale	ros-planning/moveit2
2	Planning Scene Monitor ignores planning_scene topic name #1820	Backlog	Medium	bug, E-medium, stale	ros-planning/moveit2
3	Removed collision objects linger on somewhere colliding with the robot #1775		Medium	bug, E-medium, stale	ros-planning/moveit2
4	Position constraint violated #1507	Backlog	Medium	bug	ros-planning/moveit2
5	CHOMP optimizer exits after first iteration as collision-free #1409	Backlog	Medium	question	ros-planning/moveit2
6	Don't ignore CollisionObject's pose on getKnownObjectNamesInROI #1341	Backlog	Medium	bug, E-hard	ros-planning/moveit2
7	Pilz execution fails on 'invalid transition from state EXECUTING with event ... #1337	Backlog	Medium	bug	ros-planning/moveit2
8	TOTG jump in position at the first waypoint #810	Backlog	Medium	bug	ros-planning/moveit2
9	Break out parameters for `servo publish rate` and `trajectory point d...` #2275	Backlog	Medium	enhancement	ros-planning/moveit2
10	Running a MoveIt launch file messes with terminal colors #2324	Backlog	Medium	bug, persistent	ros-planning/moveit2
	+ Add item				
	Low 11				
11	Warnings when a child-frame of a parent which is not the planning-frame is ... #1954		Low	bug, persistent	ros-planning/moveit2

All contributors are welcome! Request an invite via henningkayser@picknik.ai

Get Involved!

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Contribute to MoveIt

Review and file PRs
Engage in issue discussions
Join the meetings
Become a Core Contributor or Maintainer

GitHub

Apply for GSoC 2024

12+ weeks focused programming
Mentored by MoveIt maintainers
Details will be shared end of 2023

Google
Summer of Code

Thank You!

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