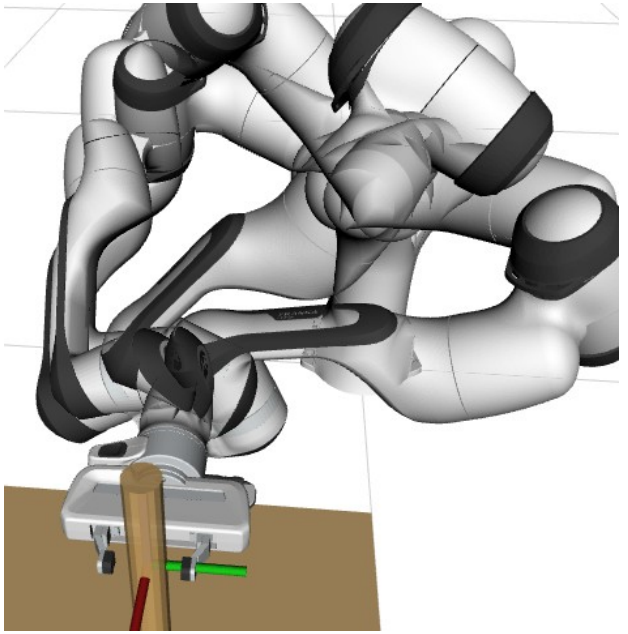
New IK Plugin API for Constraint-Based Solvers

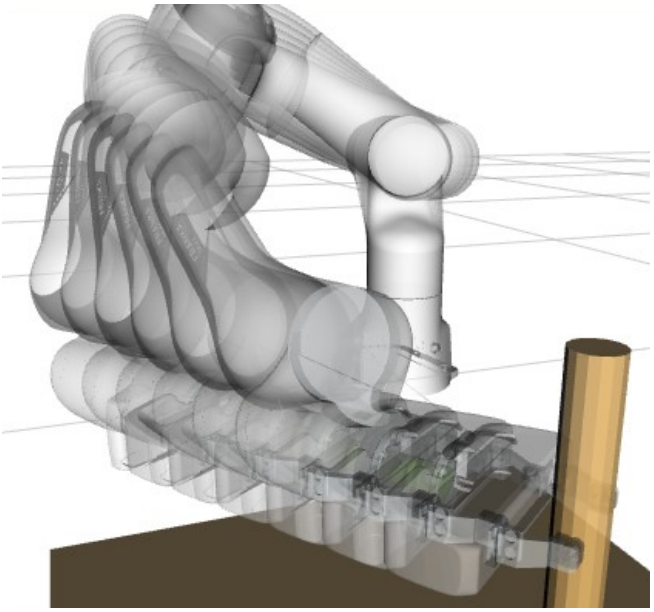
- Design flaws
- Improve support for:
  - Kinematic Trees
  - Redundancy Resolution
  - Tolerances
- Hierarchy of Tasks

Applications of IK

- Find *all* solutions for given eef pose(s) to serve as goal configs



- Compute **closest** solution to seed to get a smooth trajectory obeying Cartesian constraints



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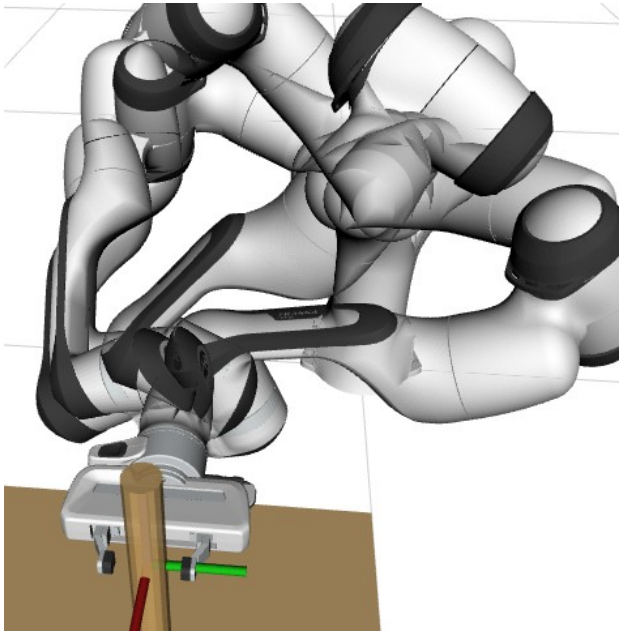

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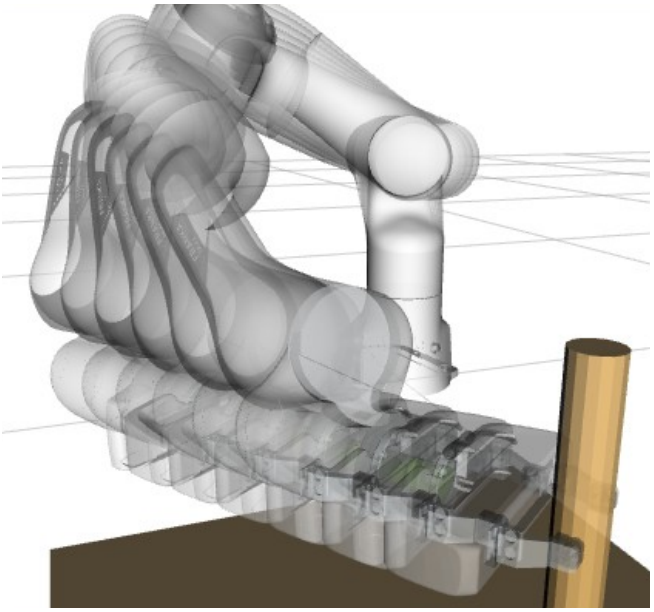
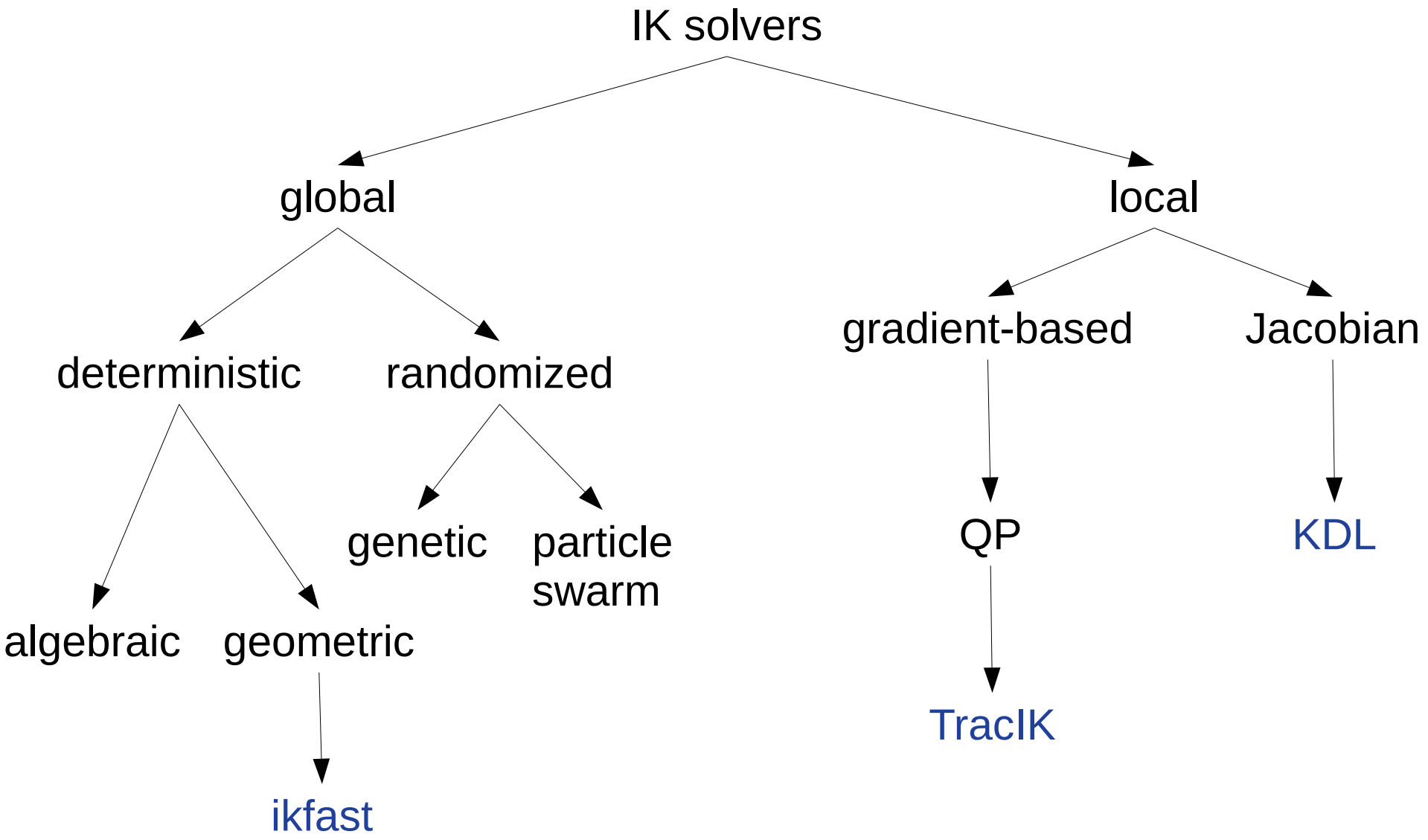


Both are not well supported by current API

IK approaches



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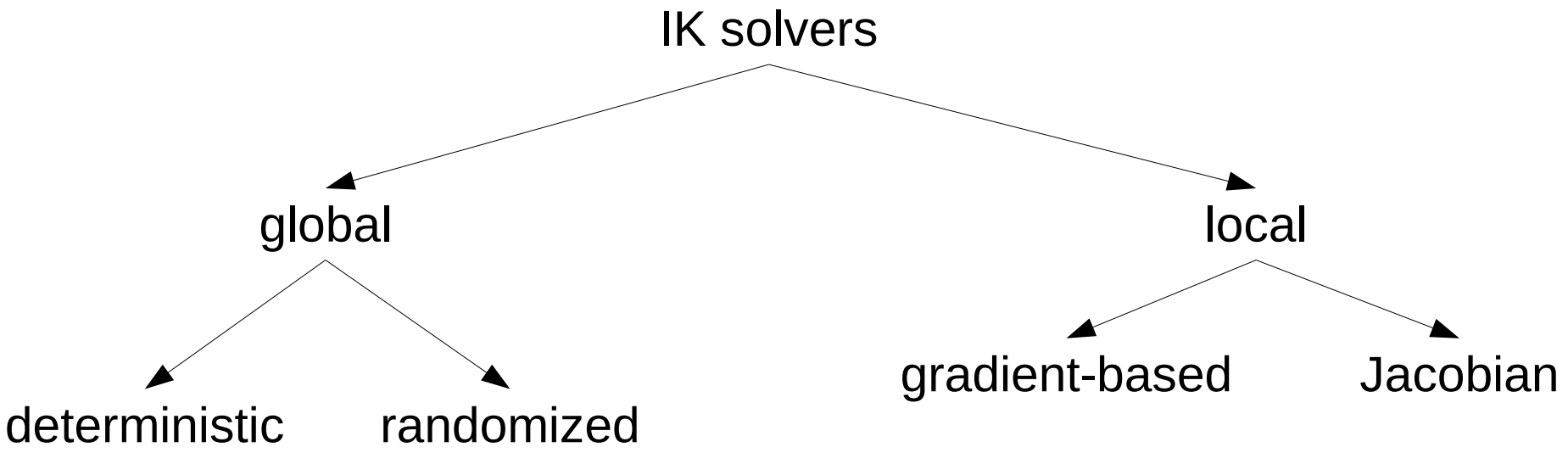

+ Enumerating all solutions
− Hard to pick a good one

+ Converging to close by solution
− Get stuck in saddles / singularities

Current IK-plugin API

- getPositionIK(pose, seed_state, solution)
  - Find (single) solution, *closest to seed state* for (single) eef
  - only used in ompl_interface::PoseModelStateSpace

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    - consistency_limits: allowed per-joint deviations from seed
    - solution_callback: validate solutions
    - most generic variant wrapped in RobotState::setFromIK()

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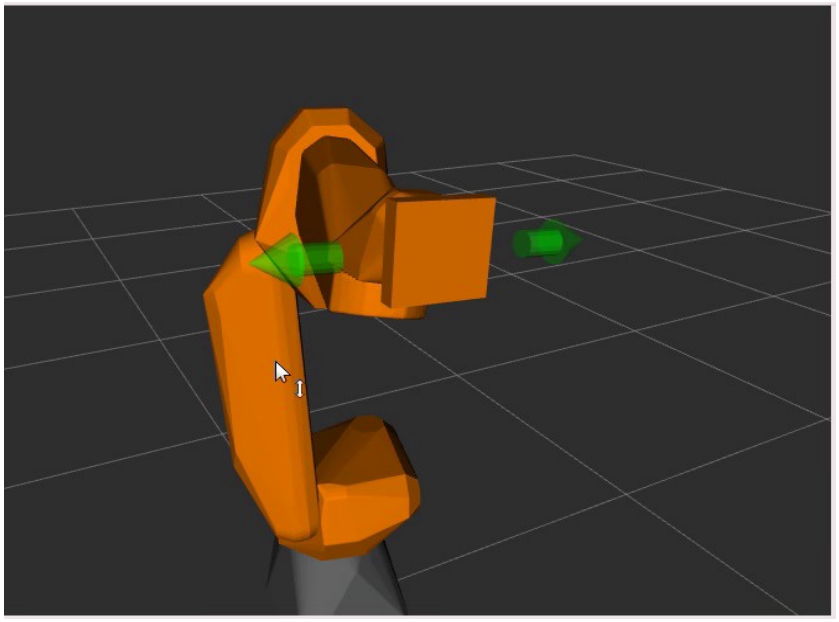
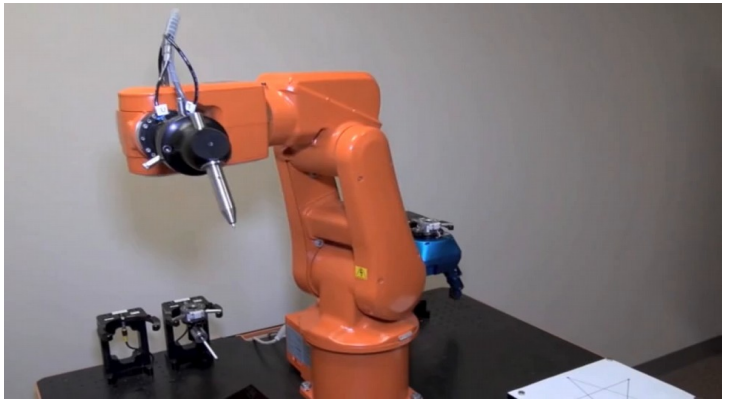
Simplify: Only keep most generic variant!

Consistency Limits

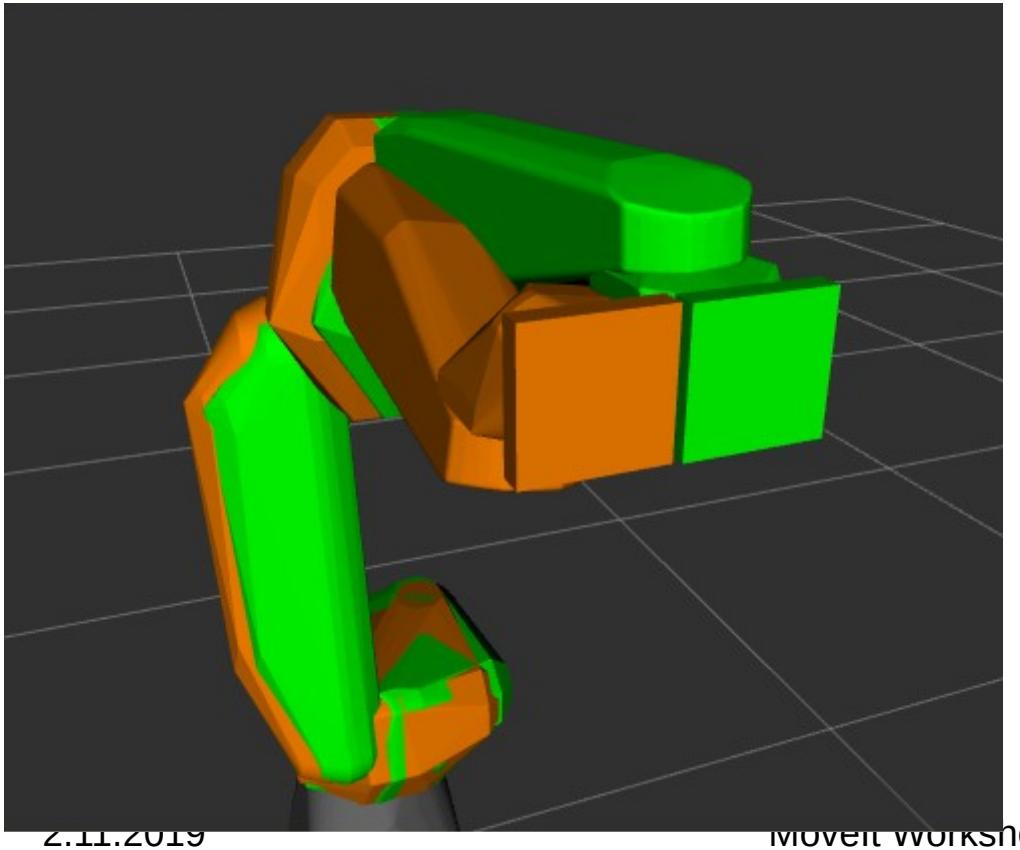
- Choosing a proper consistency limit is impossible!
- Moving through singularities results in *strong* changes in joint space





How can we do better?

- Validate *interpolation pose* between joint configs



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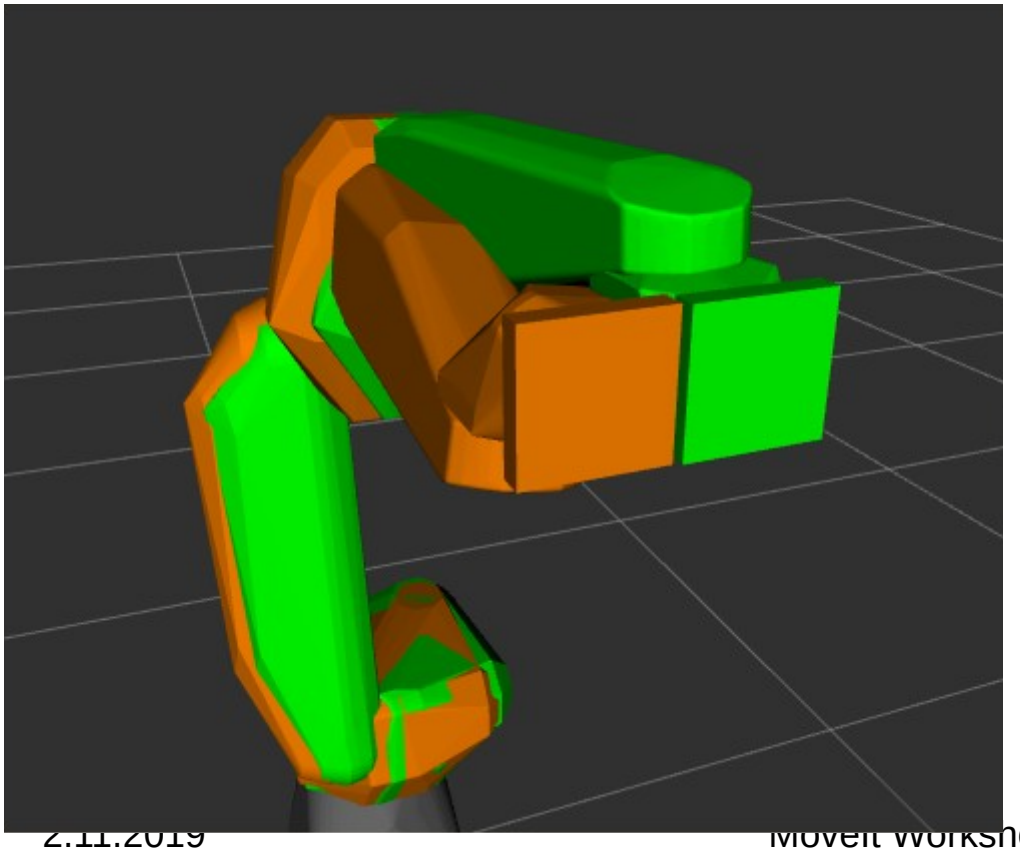

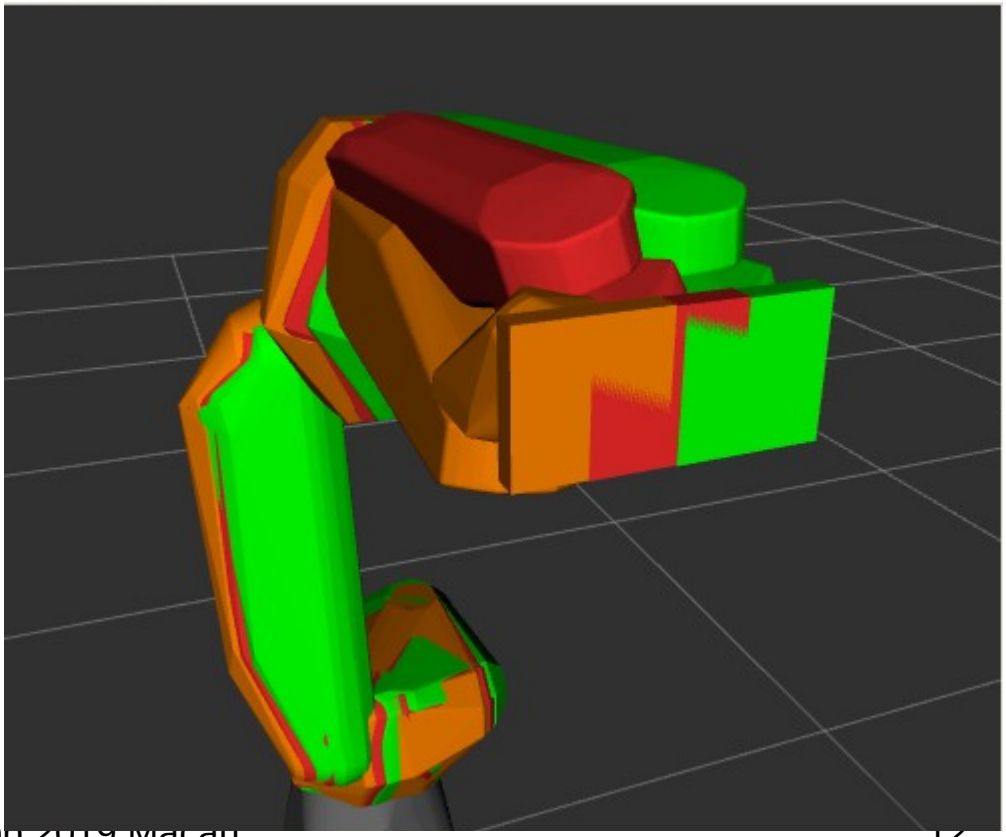

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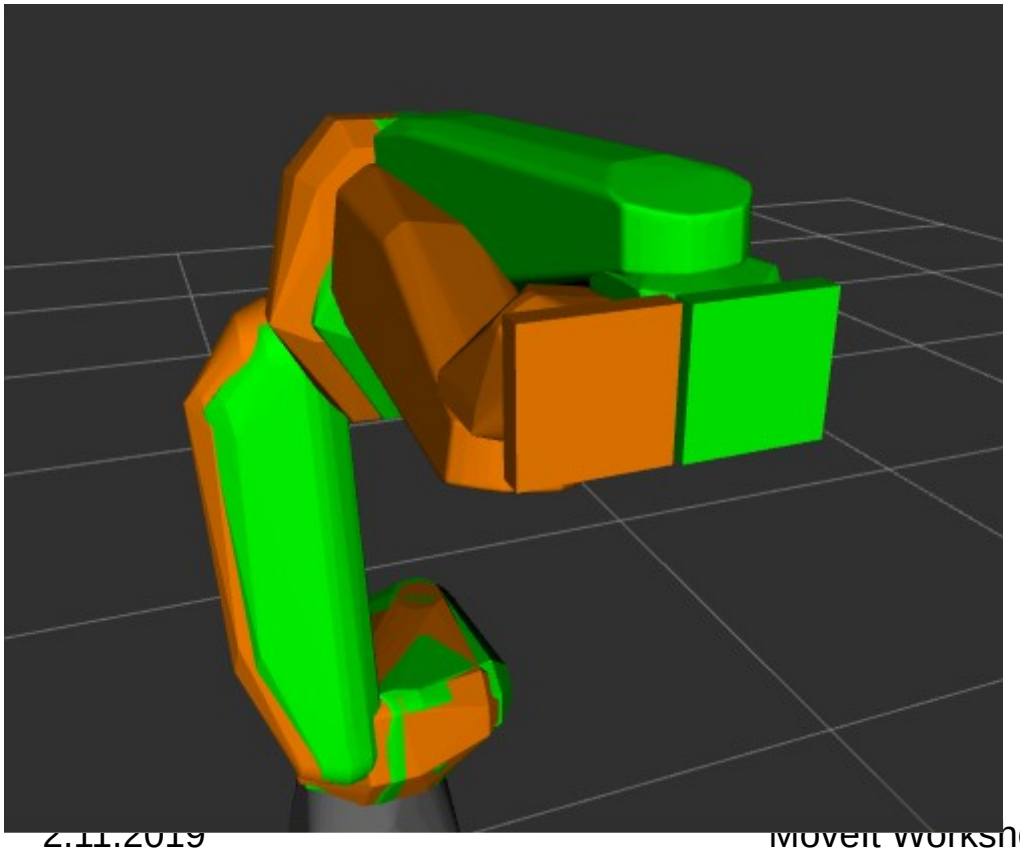
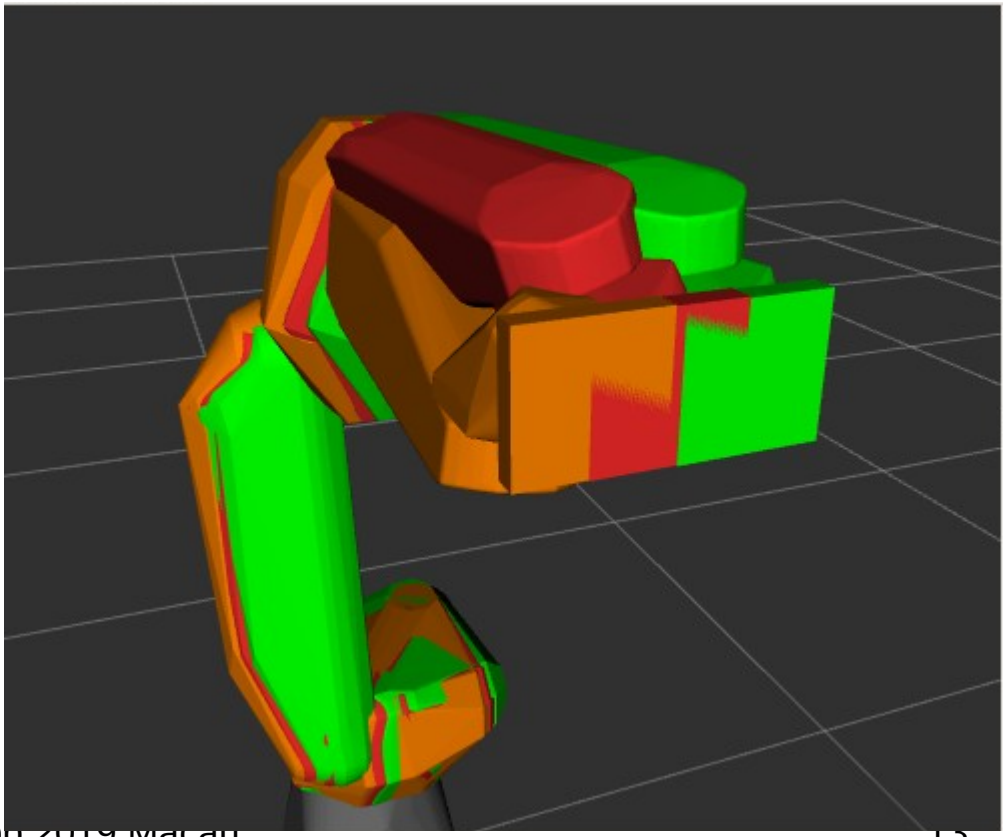
- ➔ **Provide utility function in base class to measure „distance“ between configurations**





Current API: Support for Kinematic Trees?

- Compute common solution to place multiple tips
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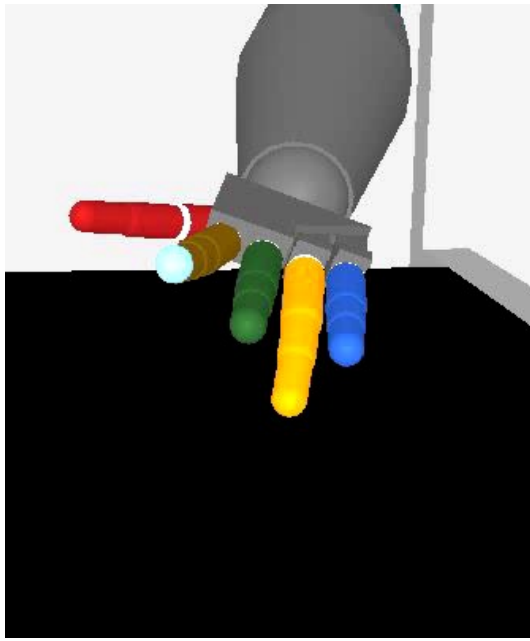

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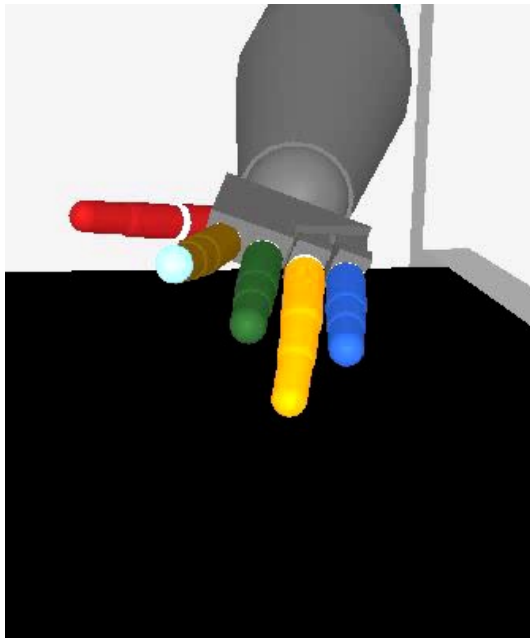

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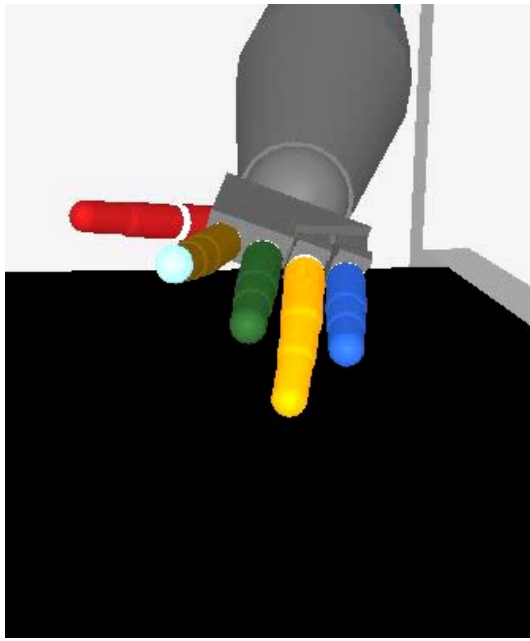

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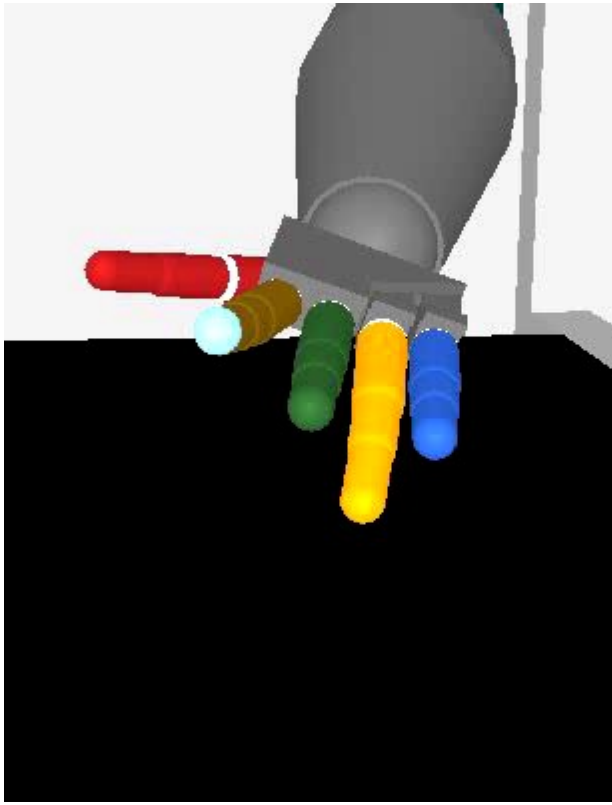

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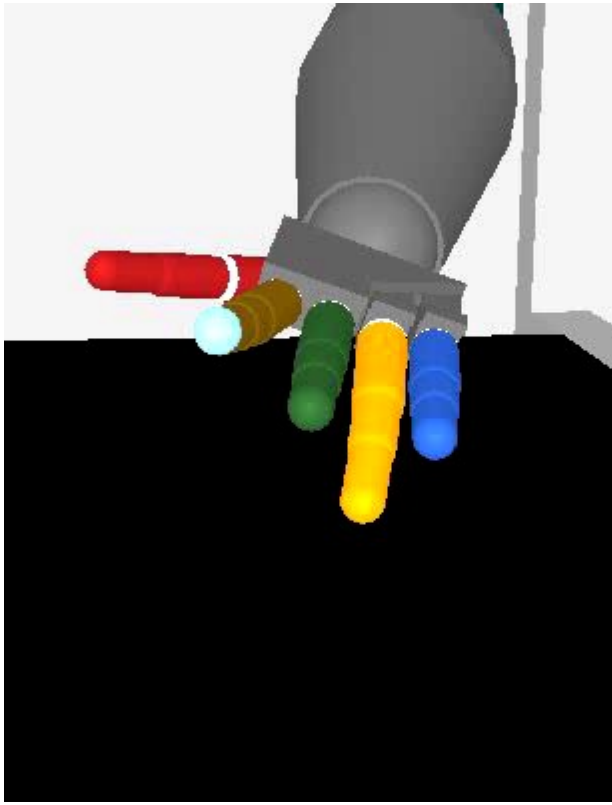
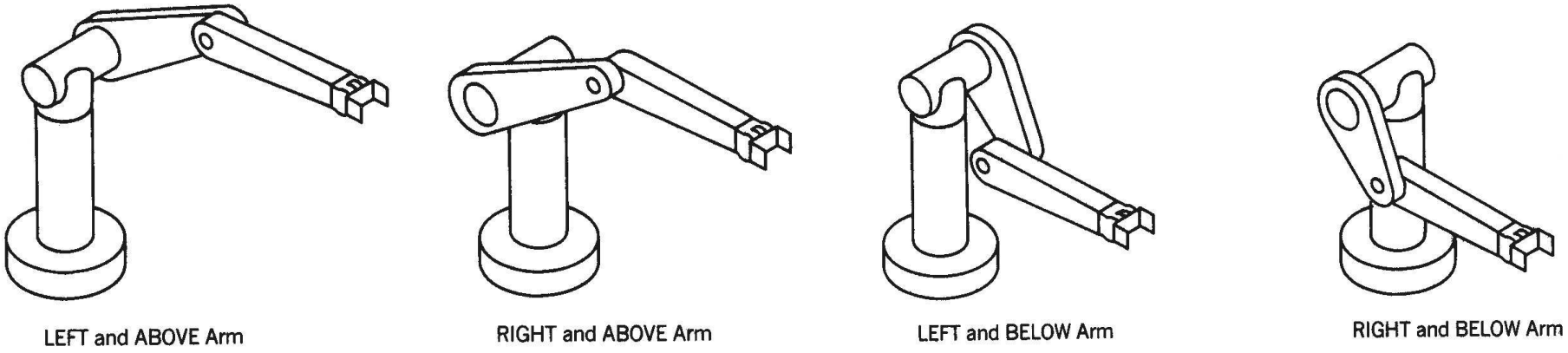


Unify: Provide similar APIs for both functions!

Supporting Redundancies

- 6-DoF robots have discrete set of redundant solutions



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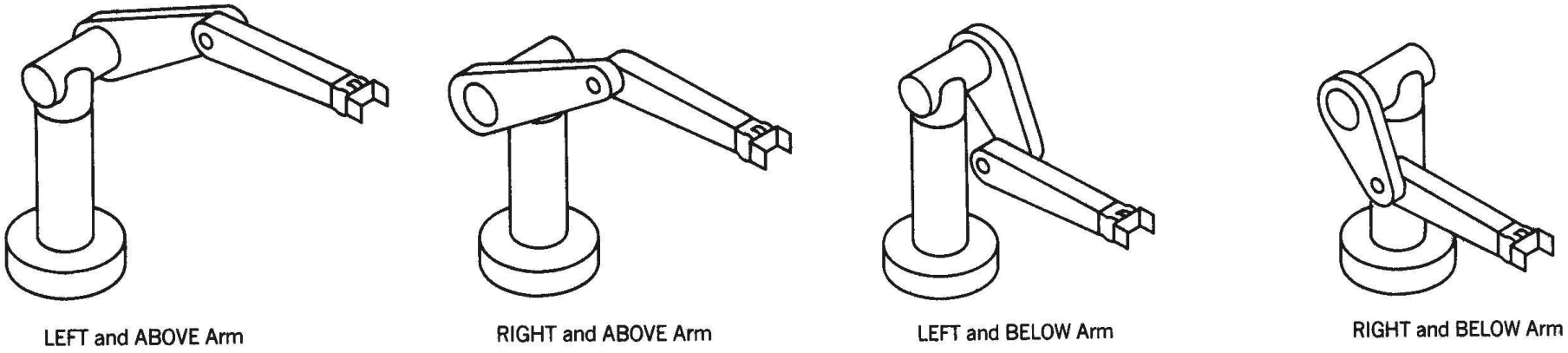

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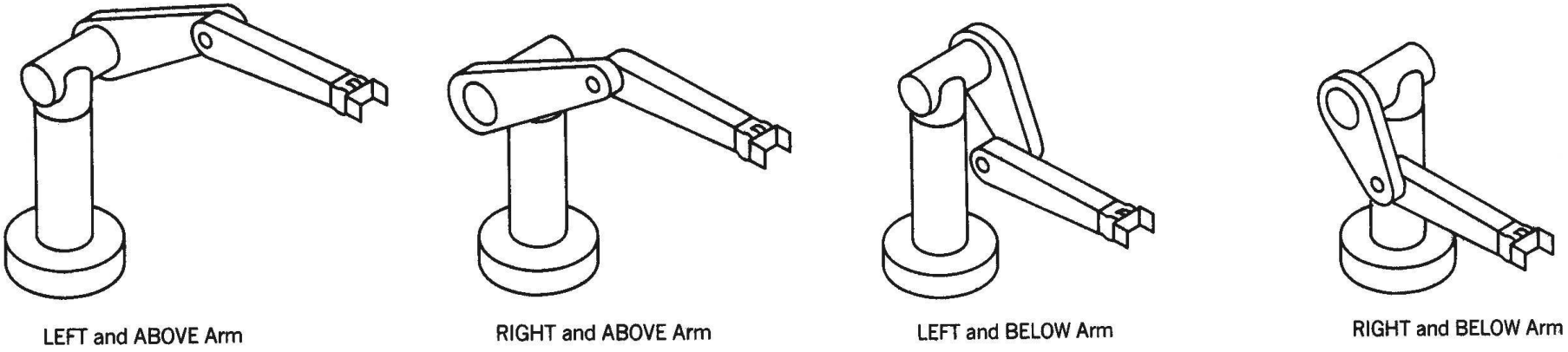

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Do we really need to find all solutions?

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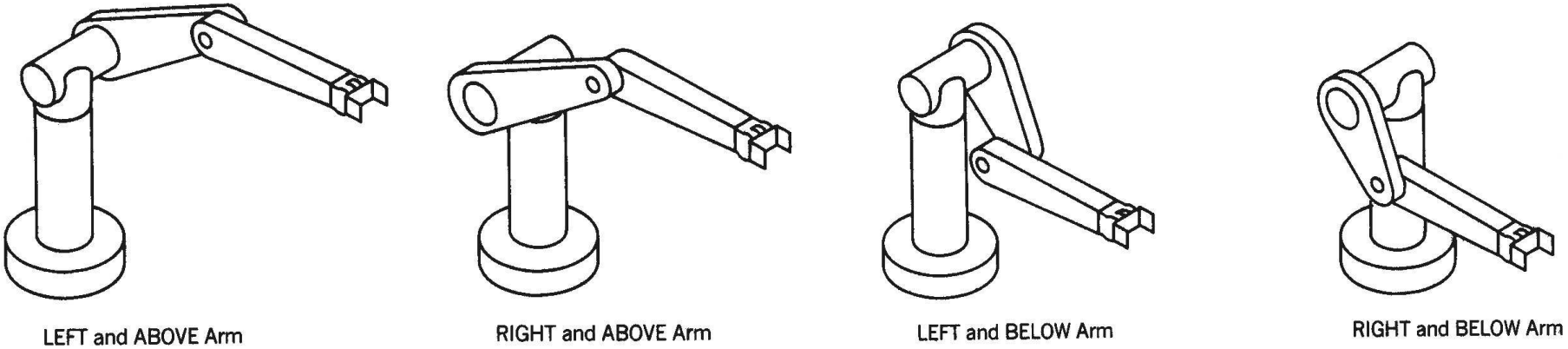
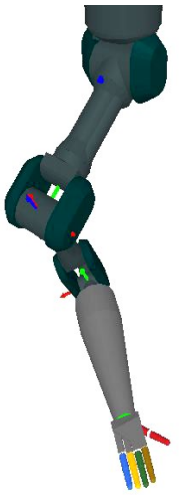


- Redundant robots (#joints > 6) *additionally* exhibit *continuous* solution manifolds
  - Finding all solutions not possible
  - Requires discretization



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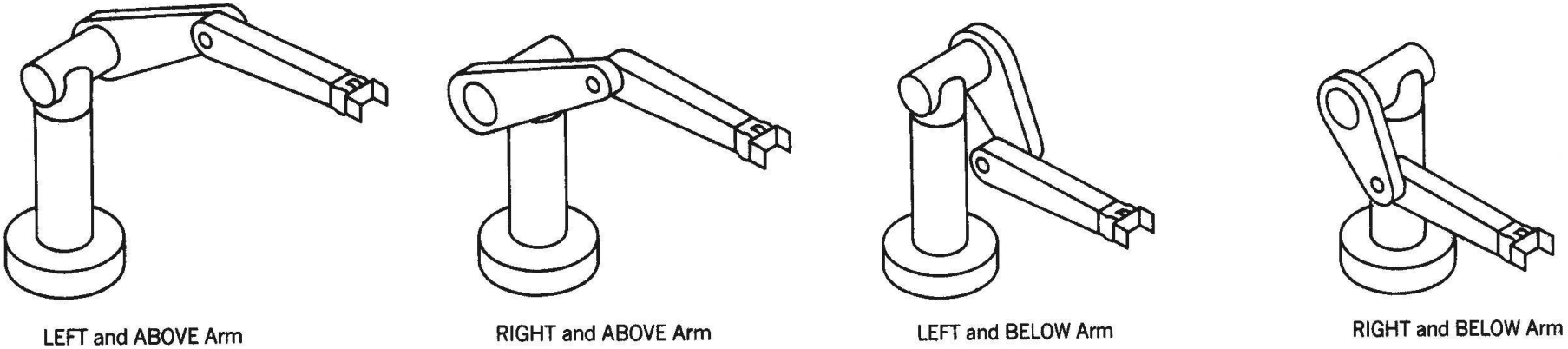

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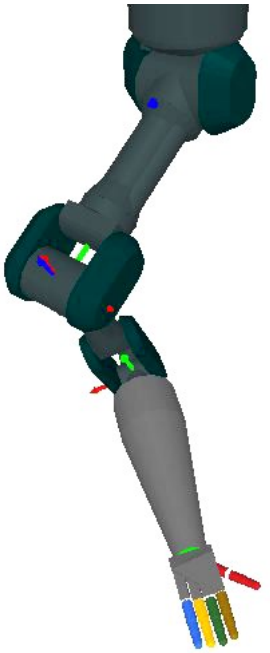


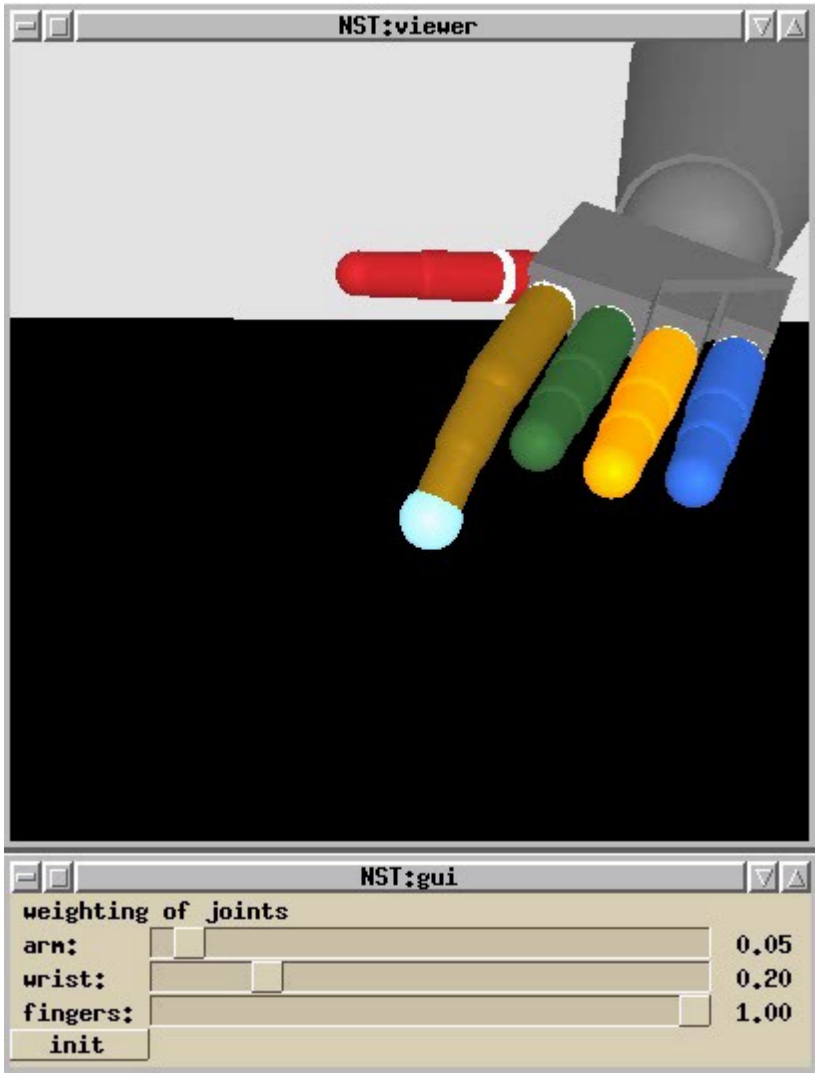
Redundancy Resolution

- No mechanism provided to resolve redundancies
- Possible Criteria:
  - Keep joints close to a „preferred“ pose / avoid limits
  - Minimize joint velocities = Jacobian Pseudoinverse
  - Minimize kinetic energy
  - Maximize manipulability
  - Minimize joint torques / effort
  - Avoid obstacles, reaching around obstacles
  - Avoid singularities

Redundancy Resolution: Joint Weighting

- Criteria usually compute a scalar cost function that is minimized
- Weighting joint contributions can yield different behaviour
- Example: Joint Velocities

- **Provide YAML params for generic distance measure?**



KinematicsQueryOptions: further arguments

- discretization_method, setRedundantJoints()
  - only relevant for specific IK solvers (e.g. ikfast)

  ➔ **move to kinematics.yaml**
- search_resolution (per redundant joint)

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- return_approximate_solution
  - used in KDL-based plugins
  - returns any not-converged solution
  - ➔ **not useful: better introduce *explicit tolerances***

Explicit Tolerances

- Allow tolerances for all Cartesian directions individually
- Creates additional DoFs in tolerance region
- Facilitates / enables IK for underactuated robots
- Example Grasping
  - position tolerance
  - orientation tolerance
  - infinite tolerance range disables Cartesian axis
  - w.r.t. a specific frame

- **Use Constraint messages?**

moveit_msgs/Constraints

```
string name
JointConstraint[] joint_constraints
PositionConstraint[] position_constraints
   std_msgs/Header header
   string link_name
   geometry_msgs/Vector3 target_point_offset
   moveit_msgs/BoundingVolume constraint_region
   float64 weight
OrientationConstraint[] orientation_constraints
VisibilityConstraint[] visibility_constraints
```

Prioritizing Goal Constraints

- Constraint messages allow weighting of tasks

$$E(\boldsymbol{\theta}) = w_1 E_1(\boldsymbol{\theta}) + w_2 E_2(\boldsymbol{\theta}) + \cdots w_n E_n(\boldsymbol{\theta})$$

- When tasks are conflicting, all fail reaching their goals

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  - order tasks by *priority*
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  - can be mixed with task weighting to merge tasks on same priority level

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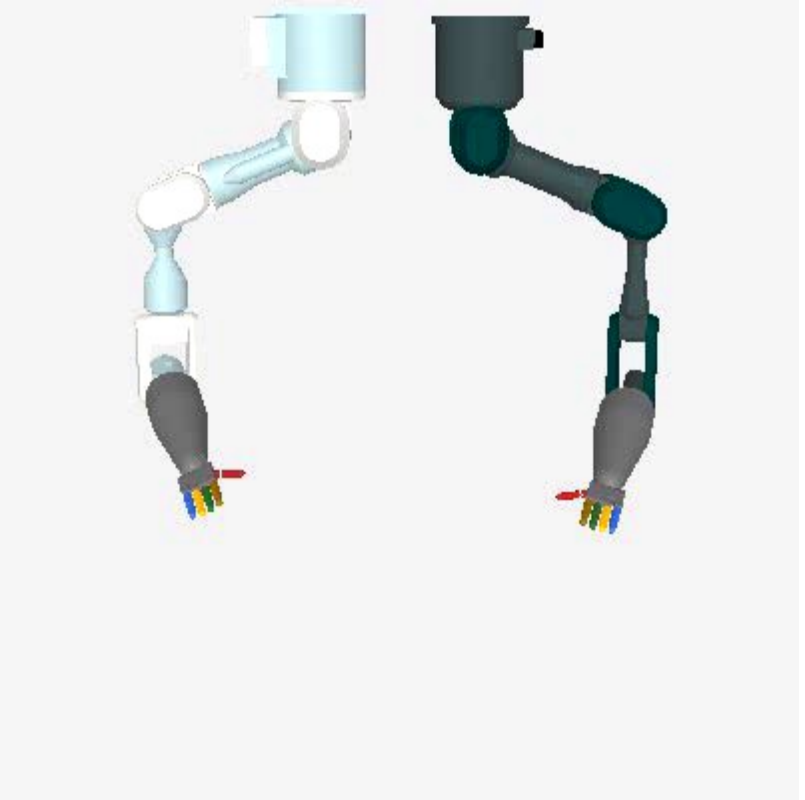
- **How could we extend Constraints messages?**

Relative Position Control

- Control left w.r.t. right hand
- Realized by simple Jacobian arithmetics

$$J = \left(\blacksquare\right) - \left(\blacksquare\right)$$

- Nullspace control: preferred pose



Summary

- Simplify, unify and clarify IK plugin API
  - **getClosestIK**(const std::**map**<string, Constraints>& goals,
    const std::vector<double>& seed_state,
    std::vector<double>& solution,
    KinematicsQueryOptions& options)
  - **getMultipleIK**(const std::**map**<string, Constraints>& goals,
    const std::vector<double>& seed_state,
    std::**list**<std::vector<double>>& solution**s**,
    KinematicsQueryOptions& options)
- Provide corresponding wrappers in RobotState
- Provide generic distance measures
  - Interpolate joint-space configs, measure Cartesian distance
  - Weighted distance from preferred joint-space config

Handling the Migration Process

- New, independent base class
- Provide generic, thin wrapper for existing IK plugins
- Failure on new constraint-based tasks
  that do not map to old IK API