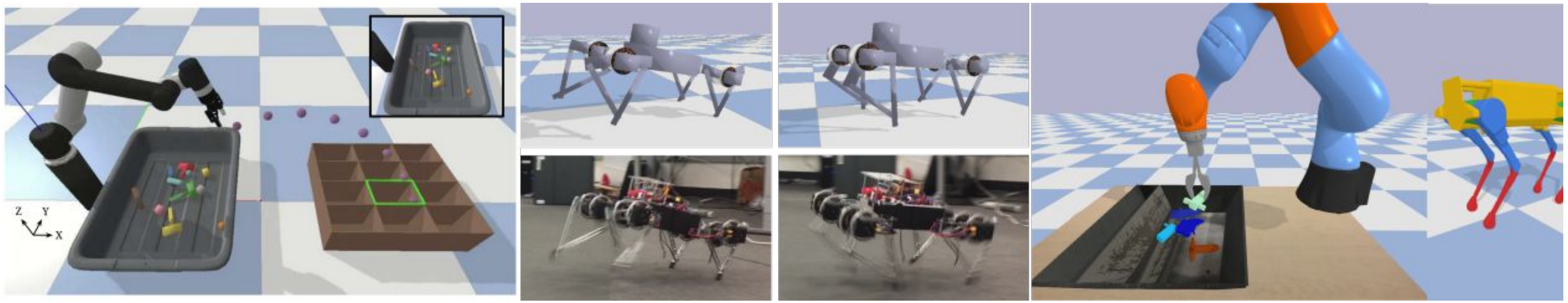
HW3 Review

Reminders

- Due Date:
    - It’s due on Friday **April 7th** at 5:00 PM EST.
    - Late submission policy is on the courseworks website.
- Submissions:
    - Submit on courseworks.
    - Check submission checklist in the handout.

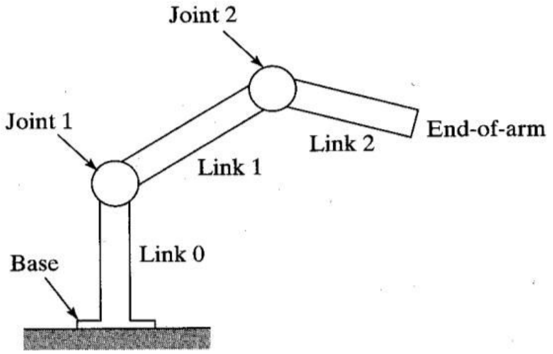
Preliminaries: Pybullet

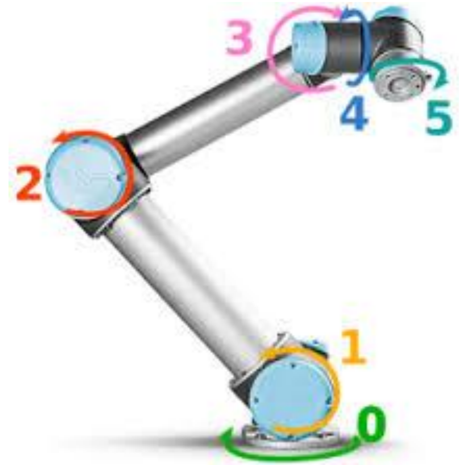
- Real-Time Physics Simulation
- QuickStart Guide

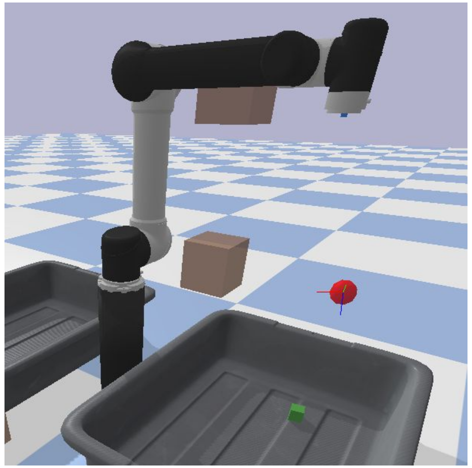


Preliminaries: UR5 Robot

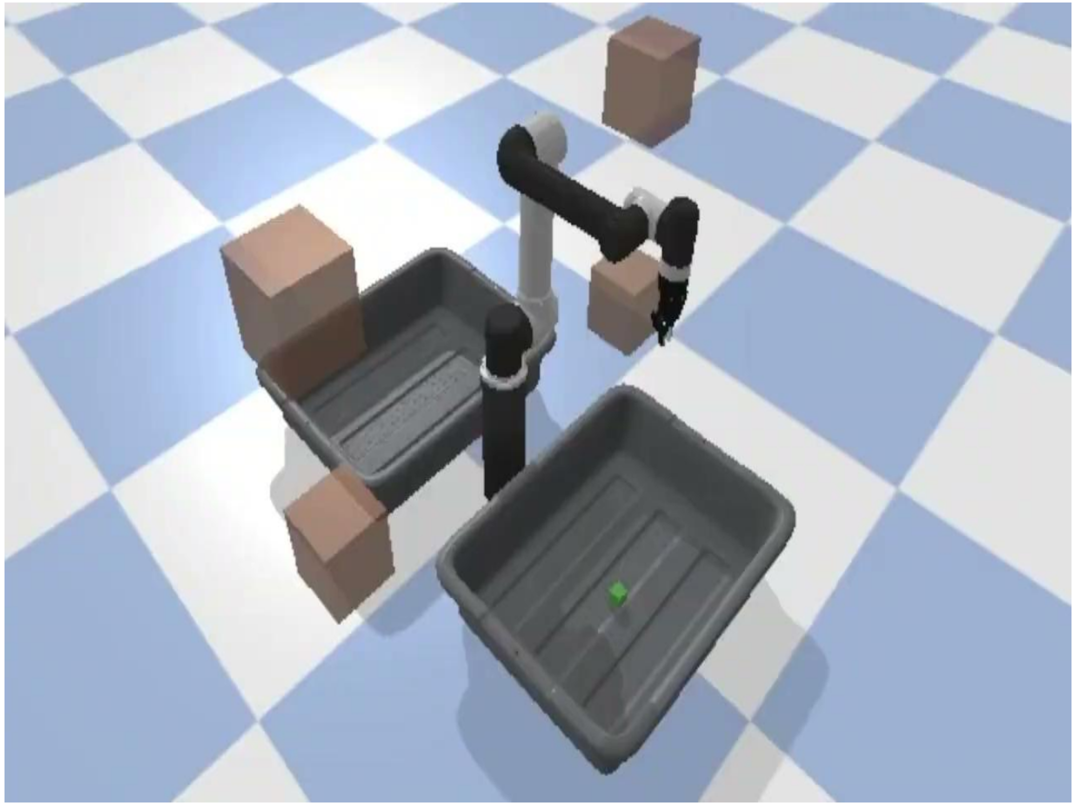
- Links, Joints (revolute, prismatic, fixed)
- # of Joints = # of Degrees of Freedom (DoF)
- Robot movement: movement of the joints
- Specified by a URDF file
- UR5: 6 revolute joints (range ± 180°)







Problem 1 Basic robot movement



Problem 1 Basic robot movement

TODOS: sim.py

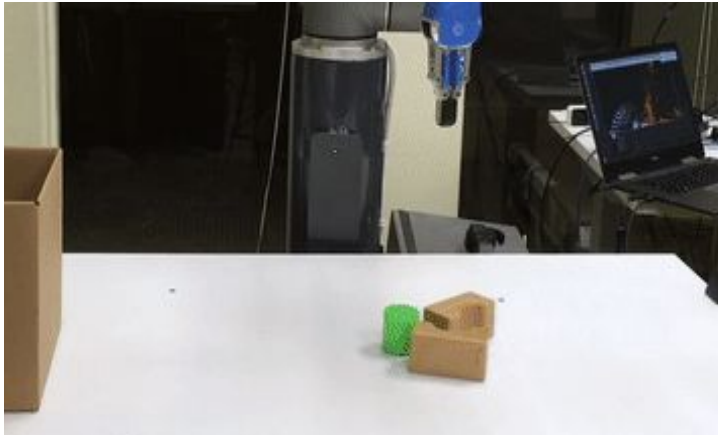
- Given a target position and orientation of the robot's end-effector, compute the values for all UR5 joint angles to reach them. (pose -> joint angles)

Hints (function and attributes you may need):

- p.calculateInverseKinematics
    - Essentially an optimization problem. For any state in configuration space, we can easily calculate the resulting pose of the end-effector (joint angles -> pose)
    - Optimize over joint configurations to reach the target pose; tune the optional parameters to optimize the configurations

      residualThreshold, ***maxNumIterations***
- PyBulletSim.robot_body_id
- PyBulletSim.robot_end_effector_link_index

Problem 2 Grasping

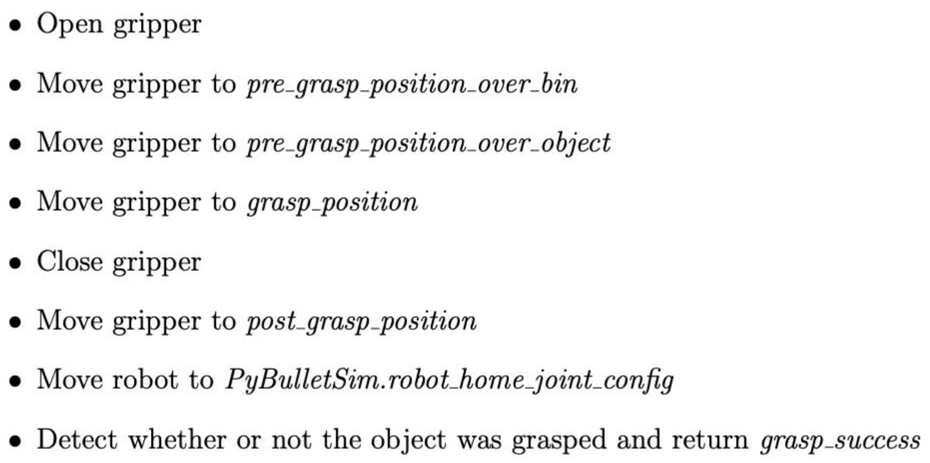


Top Down Grasping
Only need (x,y,z) and yaw (rotation about z axis)

Problem 2 Grasping

TODOS: sim.py, main.py

- Get position and orientation (in Euler angles) of the object (as the pick pose)
- Execute a pick and place action primitive
- **You should pass a test with at least 90% of times**



- Open gripper
- Move gripper to *pre_grasp_position_over_bin*
- Move gripper to *pre_grasp_position_over_object*
- Move gripper to *grasp_position*
- Close gripper
- Move gripper to *post_grasp_position*
- Move robot to *PyBulletSim.robot_home_joint_config*
- Detect whether or not the object was grasped and return *grasp_success*

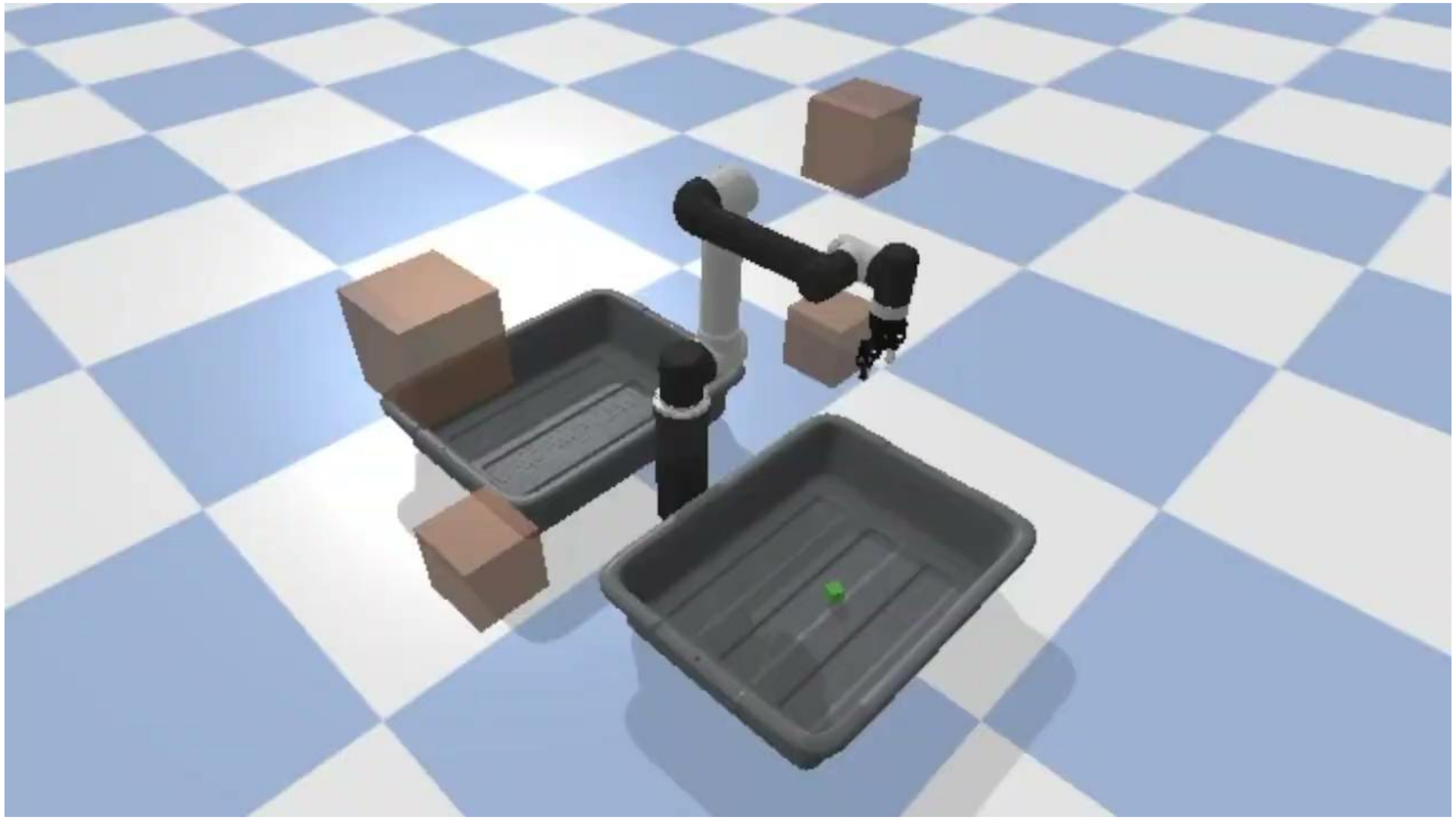
Problem 2 Grasping

Hints (some functions you may need):

- p.getBasePositionAndOrientation (returns orientation in quaternion)
- p.getEulerFromQuaternion
- PyBulletSim.open_gripper
- PyBulletSim.close_gripper
- PyBulletSim.move_tool
    - **Bug**: has a *speed* parameter, but never used
    - Pass the parameter to ***move_joints*** to control the speed
    - Decreasing movement speed may help with grasping
- PyBulletSim.robot_go_home

Problem 3 RRT

(Rapidly-exploring random tree)



Problem 3 RRT

(Rapidly-exploring random tree)

Sample New Configurations

Find nearest configuration and steer

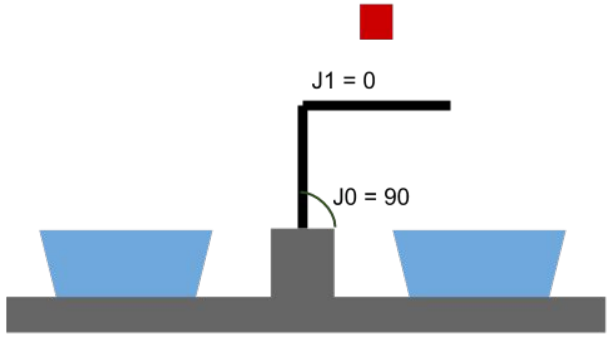
Add an obstacle-free configuration

Find the path if the new configuration is close enough
(using your favorite graph algorithm)

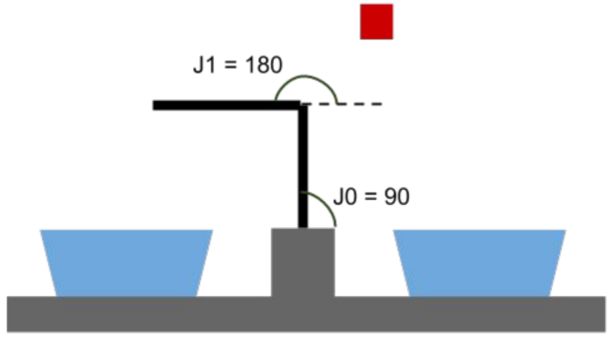
```
Algorithm rrt
    Input:
    - q_init: initial configuration
    - q_goal: goal configuration
    - MAX_ITERS: max number of iterations
    - delta_q: steer distance
    - steer_goal_p: probability of steering towards the goal
    Output:
    - path

    V <- {q_init}; E <- {}
    for i = 1 to MAX_ITERS
        q_rand <- SemiRandomSample(steer_goal_p) # with steer_goal_p
            ↪ probability, return q_goal. With (1 - steer_goal_p),
            ↪ return a uniform sample
        q_nearest <- Nearest(V, E, q_rand)
        q_new <- Steer(q_nearest, q_rand, delta_q)
        if ObstacleFree(q_nearest, q_new):
            V <- Union(V, {q_new})
            E <- Union(E, {(q_nearest, q_new)})
            if Distance(q_new, q_goal) < delta_q:
                V <- Union(V, {q_goal})
                E <- Union(E, {(q_new, q_goal)})
                path <- calculate the path from q_init to q_goal
                return path
    return None
```

Problem 3 - RRT 2D Example



Initial

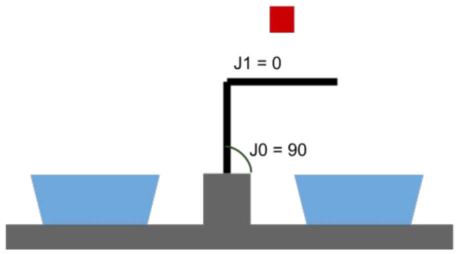


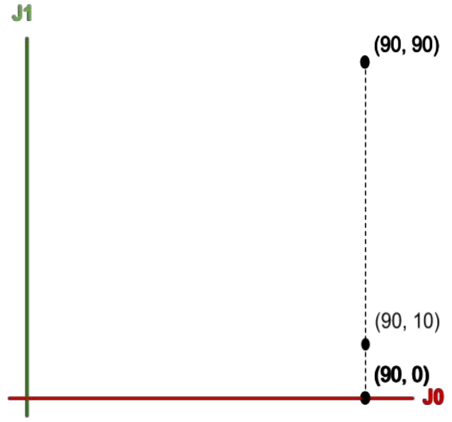
Goal

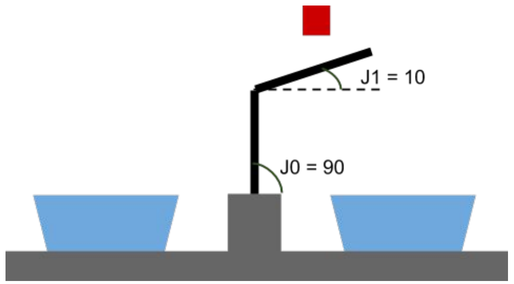
delta_q = 10

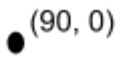
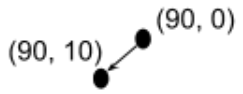
Problem 3 - RRT 2D Example

Sample (90, 90)



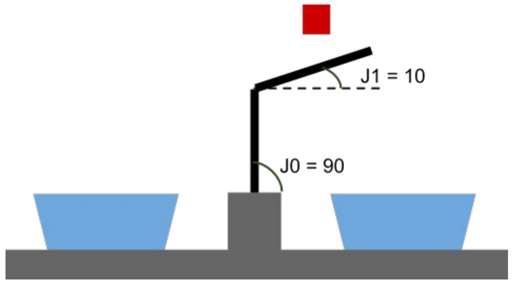


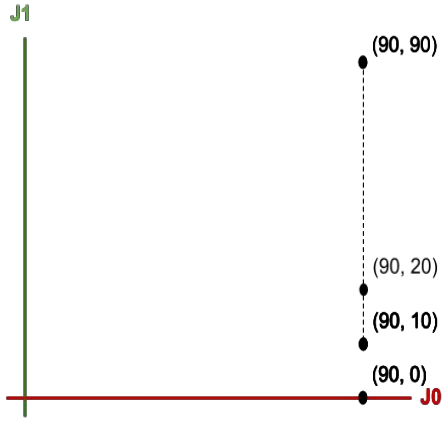


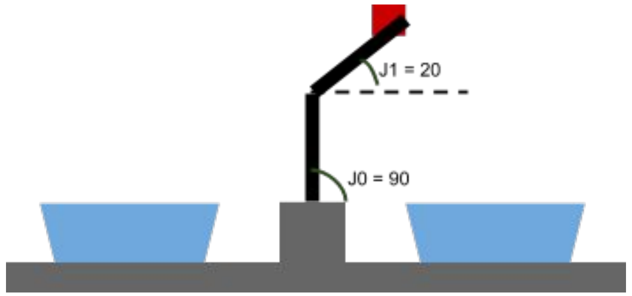
Tree	Propose Random	Nearest Node	Steer	Check Collision	Add to tree
	(90, 90)	(90, 0)	(90, 10)	None	

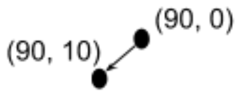
Problem 3 - RRT 2D Example

delta_q = 10



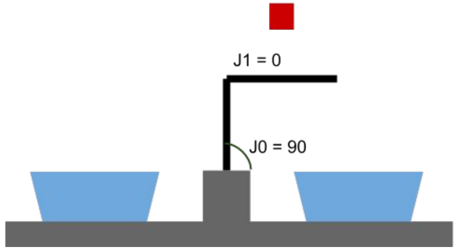


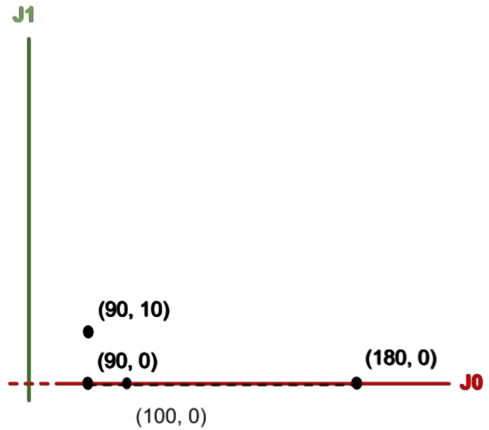


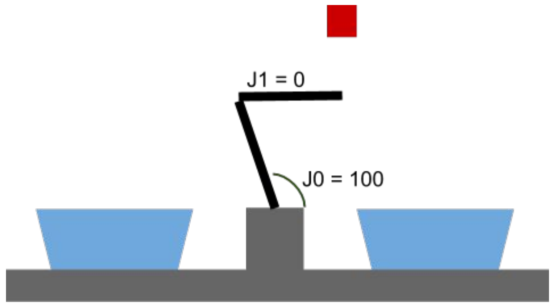
Tree	Propose Random	Nearest Node	Steer	Check Collision	Add to tree
	(90, 90)	(90, 10)	(90, 20)	Yes	

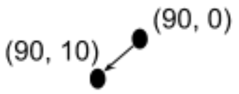
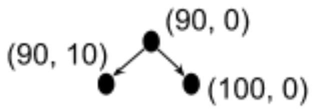
Problem 3 - RRT 2D Example

delta_q = 10







Tree	Propose Random	Nearest Node	Steer	Check Collision	Add to tree
	(180, 0)	(90, 0)	(100, 0)	No	

Problem 3 RRT

(Rapidly-exploring random tree)

- State space
  - 6DoFs of UR5, each DoF has range [-π, π]
  - View them as 6D vectors
  - May be helpful to implement as numpy arrays
- Distance metric
  - Possible choices,
    - $$d_1 = ||p-q||_1 = \sum_{i=1}^{6} |p_i - q_i|$$
    - $$d_2 = ||p-q||_2 = \sqrt{\sum_{i=1}^{6} (p_i - q_i)^2}$$
    - $$d_3 = \sum_{i=1}^{6} \min(2\pi - |p_i - q_i|, |p_i - q_i|)$$
  - Note: be cautious with units (radians or degrees), and modify ***delta_q*** accordingly
- Steer $$q_{new} = q_{near} + (q_{rand} - q_{near}) * \frac{\delta_q}{d(q_{rand}, q_{near})}$$

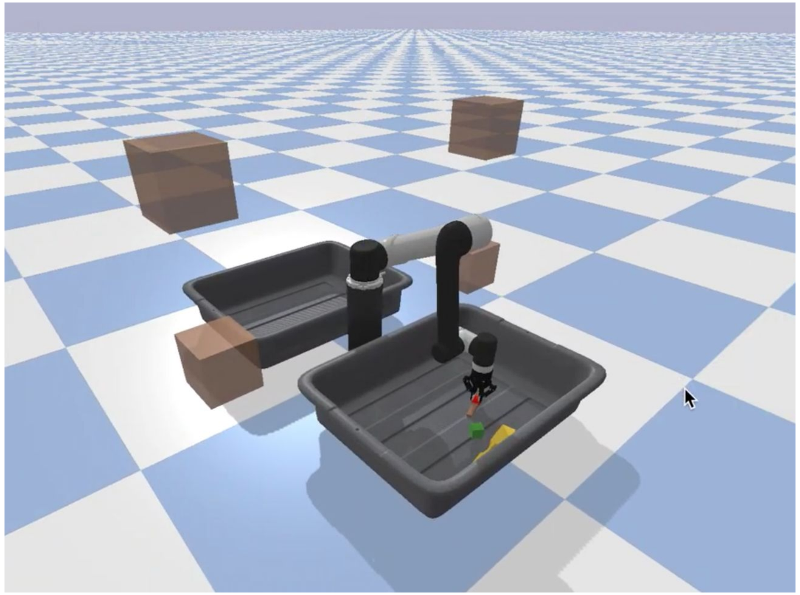
Problem 3 RRT

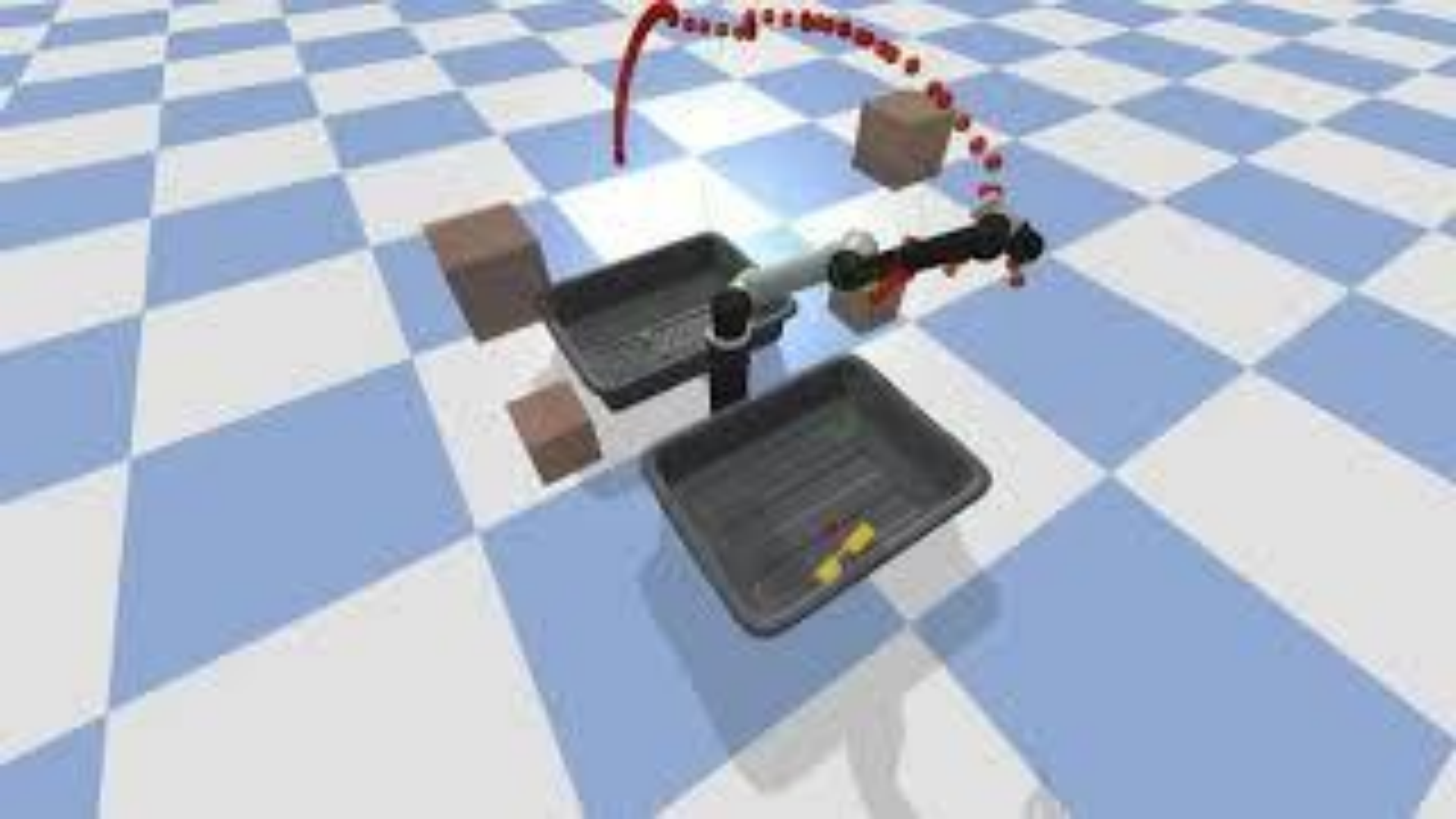
(Rapidly-exploring random tree)

- Check obstacle free: ***check_collision()***
  - Technically, should check every point along the path
  - For this assignment, we will assume ***delta_q*** is sufficiently small and check the end configurations only
  - Note: to implement this, we moved the robot to the configuration and check if there is collision, so it's normal for the robot to "shake around" during path finding
- Error: "***Timeout: robot is taking longer than 5s to reach the target joint state. Skipping...***"
  - This means your robot didn't get to the specified joint configuration within 5s.
  - Increase speed (to 0.1) when invoking ***move_joints*** may solve the problem
  - It may get stuck when executing the command, check if your robot runs into a obstacle
  - It's possible that ***delta_q*** is too large so the robot runs into collision (as aforementioned, we didn't check collision along the path)
- **You should pass a test with at least 90% of times**

Problem 4 (20% Extra Credits)

- Task: Transfer all objects to another bin
- Challenge: Ground truth object pose is not available
- Solution: Use RGBD images and object 3D model to obtain grasp pose



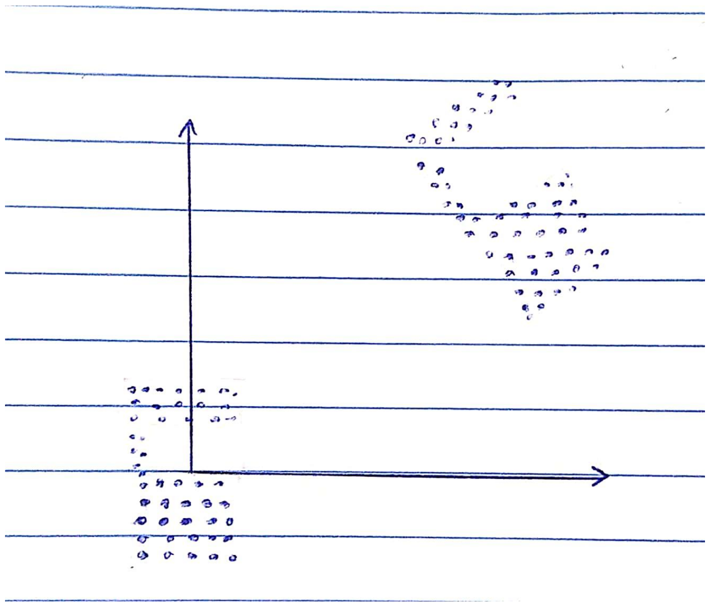


Figuring out the object pose

Input: Current observation of a known object as a *point cloud*

Output: the object pose

Solution: ICP

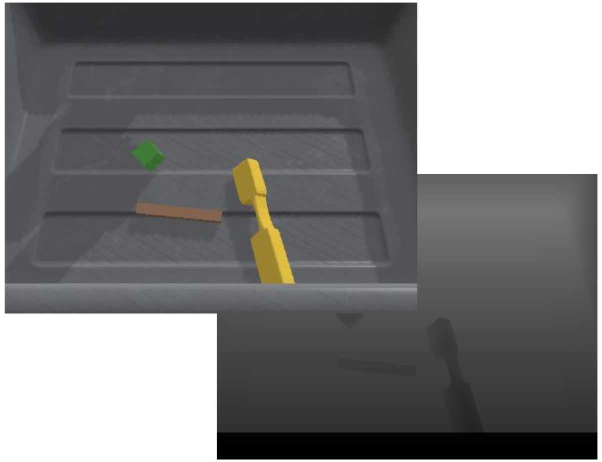


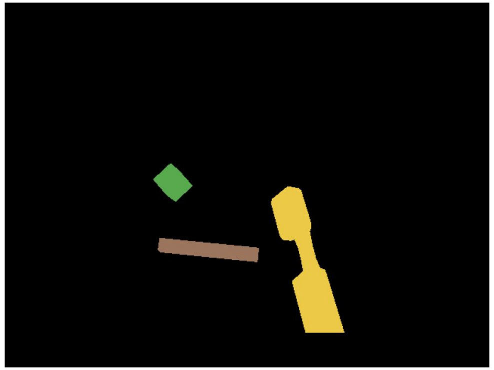
Get object point cloud

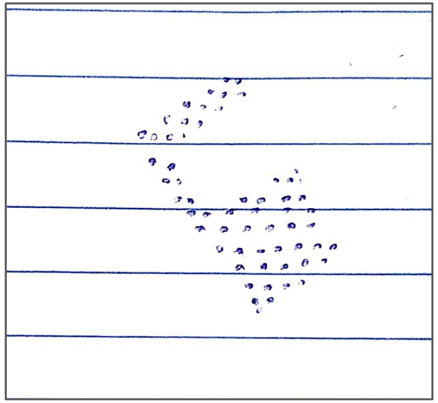
Input: Current observation of the scene as a *RGBD image*

Output: Current observation of the object as a *point cloud*

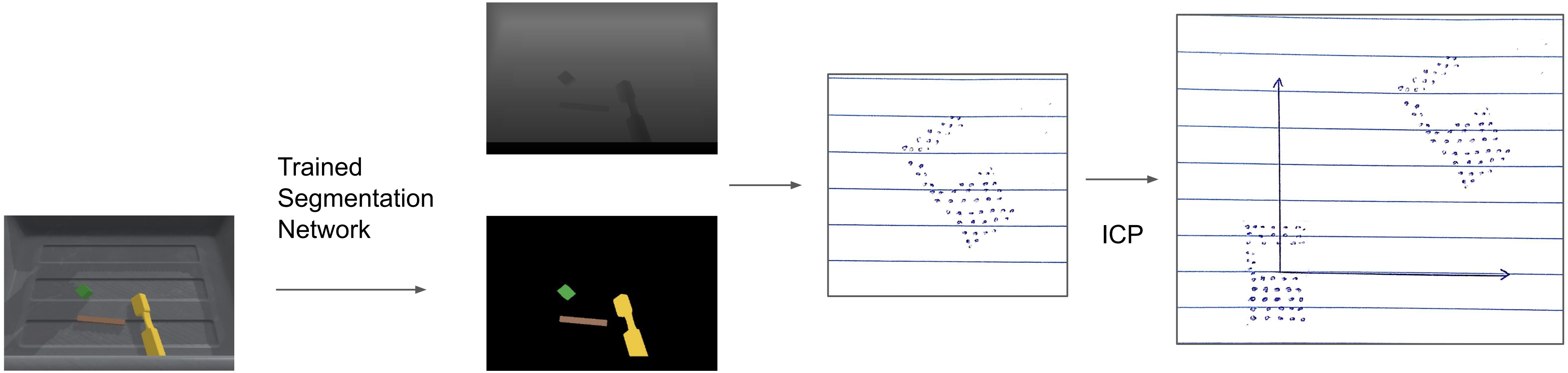
Solution: Semantic Segmentation







Overall pipeline



Some additional notes

- In this project, we will assume that the grasp pose is the object pose. In reality, it’s itself a hard problem to figure out a good grasp pose.
- It's fine if the robot needs a few tries to grasp an object.
- It's possible that objects fall off during path execution, or the objects do not fall off even when the gripper opens. It's fine as long as your robot picks the object up, finds the correct path, and executes all the required actions.
- It's also possible that objects are initialized with hard poses so that robot cannot pick them up. You can simply try to re-run the script, or reset objects in the script.

Q & A Time