Differentiable Physics and Stable Modes for Tool Use and Manipulation Planning

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Motivation and Main Problem

1-5 slides

High-level description of problem being solved

Why is the problem important?

❖ its significance towards general-purpose robot autonomy

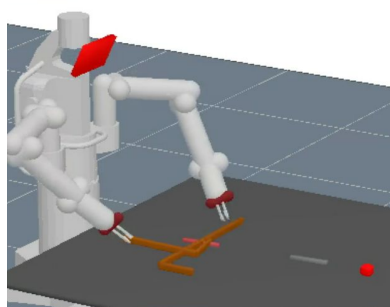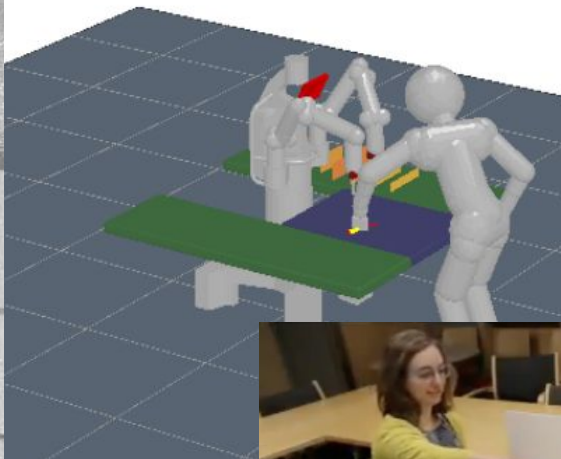❖ its potential application and societal impact of the problem

Technical challenges arising from the problem

❖ the role of the AI and machine learning in tackling this problem

High-level idea of why prior approaches didn't already solve

Key insight(s) (try to do in 1-3) of the proposed work

Motivation and Main Problem
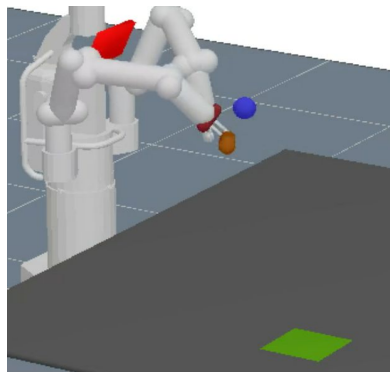
Motivation and Main Problem

Technical challenges

Inverting a physical simulator is challenging

Differentiable Physics Engines

If we had fully (auto-) differentiable physical simulations, in principle, we could invert a simulation to determine the initial conditions and control inputs by constraining the end result.

Differentiable Physics Engines

However, inverting such a simulation efficiently remains a challenge. As the paper elucidates, the complexity of inverting a physical simulator is evident in the non-unimodality of the optimization problem it presents.

Motivation and Main Problem (continues)

The role of the AI and machine learning in tackling this problem

They use traditional AI (STRIPS)

What is the key limitation of prior work

Prior works did not put two things together (differentiable physics and TAMP)

What is the key insight(s) (try to do in 1-3) of the proposed work

Hierarchical planning, use of modes

Context / Related Work / Limitations of Prior Work

1 or more slides

Which other papers have tried to tackle this problem or a related problem?

❖   The paper's related work is a good start, but there may be others

❖   What is the key limitations of prior work(s)?

Context / Related Work / Limitations of Prior Work

Lack of Integration with Higher-level Planning:
Contact-Invariant Optimization
- **haven't been demonstrated to connect with higher level too use**

Does not include physical primitives:
Toussaint and Lopes [31, 32] proposed an optimization-based approach:
- **logic task-level description**
- **non-linear programming formulation of the optimization problem.**
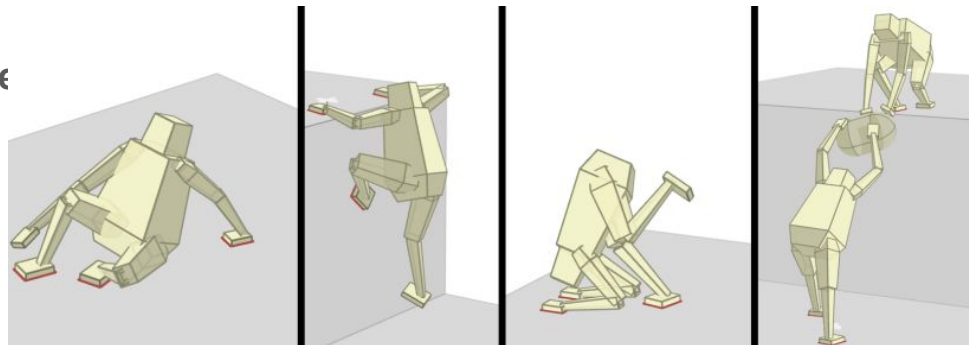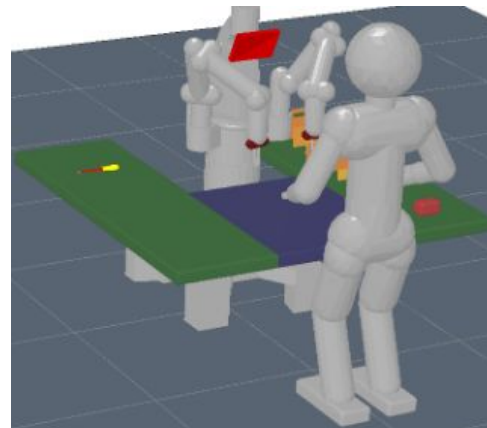
Problem Setting

1 or more slides

Problem formulation, key definitions and notations

❖ Be precise -- should be as formal as in the paper

Problem Setting

Logic-Geometric Program (LGP)

terminal cost · running cost

$$\min_{u} J(u) := K(x(T)) + \int_0^T L\big(t, x(t), u(t)\big) dt$$

$$s.t.\ x(t) \in X, \forall t \in [0, T] \qquad \text{state constraints}$$

$$x(0) = x_0, \qquad x(t + \Delta t) = f(x, u, \Delta t) \qquad \text{dynamic constraints}$$

control constraints $\quad u(t) \in U, \forall t \in [0, T]$

inequality constraints $\quad g_{i(x(t))} \leq 0\ \forall i \in [0..L], \forall t \in [0, T]$

equality constraints $\quad h_{i(x(t))} = 0\ \forall i \in [0..L], \forall t \in [0, T]$

We aim to find a path $x : [0, T] \to \mathcal{X}$

Logic-Geometric Program

$$\min_{u} J(u) := K\big(x(T)\big) + \int_0^T L\big(\bar{x}(t)\big)dt$$

$$s.t. \ x(0) = x_0, h_{goal}\big(x(T)\big) = 0, g_{goal}\big(x(T)\big) \leq 0$$

$$\forall t \in [0, T] : h_{path}\big(\bar{x}(t), s_{k(t)}\big) = 0$$

$$g_{path}\big(\bar{x}(t), s_{k(t)}\big) \leq 0$$

$$\forall k \in [1, .., K] : h_{switch}\big(\hat{x}(t_k), a_k\big) = 0$$

$$g_{switch}\big(\hat{x}(t_k), a_k\big) \leq 0$$

$$s_k = f(s_{k-1}, a_k)$$

$$\bar{x} = (x, \dot{x}, \ddot{x})$$
$$\hat{x} = (x, \dot{x}, \dot{x}_{new})$$
$$a_{1:K} \Rightarrow \text{skeleton}$$

Proposed Approach / Algorithm / Method

1-5 slides

Describe algorithm or framework (pseudocode and flowcharts can help)

❖ What is the optimization objective?

❖ What are the core technical innovations of the algorithm/framework?

Implementation details should be left out here, but may be discussed later if its relevant for limitations / experiments

Proposed Approach / Algorithm / Method

Dynamic physical manipulations in a Task and Motion Planning (TAMP) framework.

Merges a discrete logic level, which represents sequences of possible interaction modes (action operator), with a continuous path optimization level.

How to generate the new state imposed by the symbolic action?

Use a classical STRIPS system!

pre state

(table desk)
(object ball) ✔
(object stick)
(gripper baxterR) ✔
(gripper baxterL)
not(busy baxterR) ✔
not(busy baxterL)
not(held ball) ✔
not(held stick)
. . .

Decision Rule = possible

grasp   X   Y

X = baxterR
Y = ball

post state

(table desk)
(object ball)
(object stick)
(gripper baxterR)
(gripper baxterL)
(busy baxterR)
not(busy baxterL)
(held ball)
not(held ball)
+(grasped baxterR ball)
+komo(inside baxterR ball)
+komo(effFree baxterR ball)
. . .

✔ ✔ ✔ ✔

Precond { (gripper X) (object Y) not(busy X) not(held Y) }
Effects { (grasped X Y) (busy X) (held Y) komo(inside X Y) komo(effFree X Y) }

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TABLE I
PREDICATES TO IMPOSE CONSTRAINTS ON THE PATH OPTIMIZATION.

(touch X Y)	distance between X and Y equal 0
[impulse X Y]	ImpulseExchange eq & skip smoothness constraints on X Y
(staFree X Y)	create stable (constrained to zero velocity) free (7D) joint from X to Y
(staOn X Y)	create stable 3D $xy\phi$ joint from X to Y
(dynFree X)	create dynamic (constrained to gravitational inertial motion) free joint from world to X
(dynOn X Y)	create dynamic 3D $xy\phi$ joint from X to Y
(inside X Y)	point X is inside object Y $\rightarrow$ inequalities
(above X Y)	Y supports X to not fall $\rightarrow$ inequalities
(push X Y Z)	(see text)

TABLE II
ACTION OPERATORS AND THE PATH CONSTRAINTS THEY IMPLY.

grasp(X Y)	[inside X Y] (staFree X Y)
handover(X Y Z)	[inside Z Y] (staFree Z Y)
place(X Y Z)	[above Y Z] (staOn Z Y)
throw(X Y)	(dynFree Y)
hit(X Y)	[touch X Y] [impulse X Y] (dynFree Y)
hitSlide(X Y Z)	[touch X Y] [impulse X Y] (above Y Z) (dynOn Y Z)
hitSlideSit(X Y Z)	"hitSlide(X Y Z)" "place(X Z)"
push(X, Y, Z)	komo(push X Y Z)

Lower Level


```
time:1/34 | cost for each level:   0.6 0 0 1237.41 | constraint violation:304.351
-----------------------------------------------------------------------
(grasp baxterR stick2)                    StepsPerPhase:5
(push stickTip2 stickTip table1)          Newton Steps:0
(place baxterR stick2 table1)             mu:4
(grasp baxterL stick)                     nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)
```
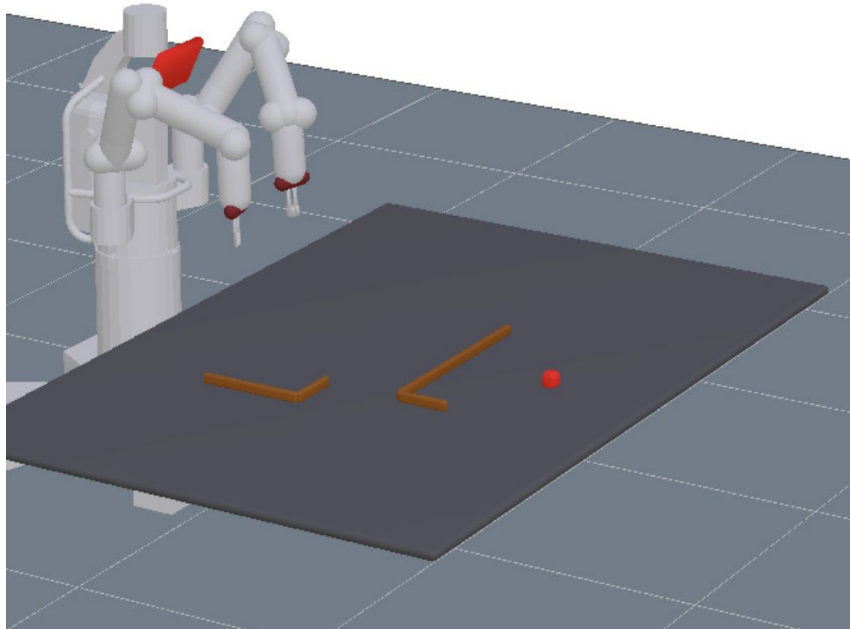
Constraint Optimization Problem

- **Optimize the full path of the configuration space along constraints**

- **different phases = kinematic modes are imposed by constraints**

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time:1/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:1/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:2/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:2/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:3/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:3/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
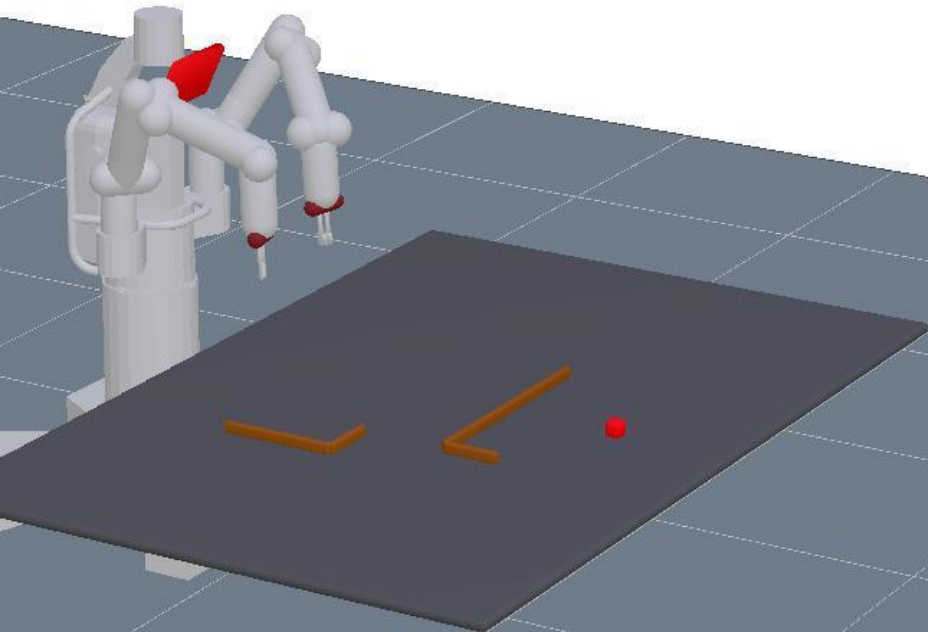(push stickTip redBall table1)
(grasp baxterR redBall)

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time:4/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
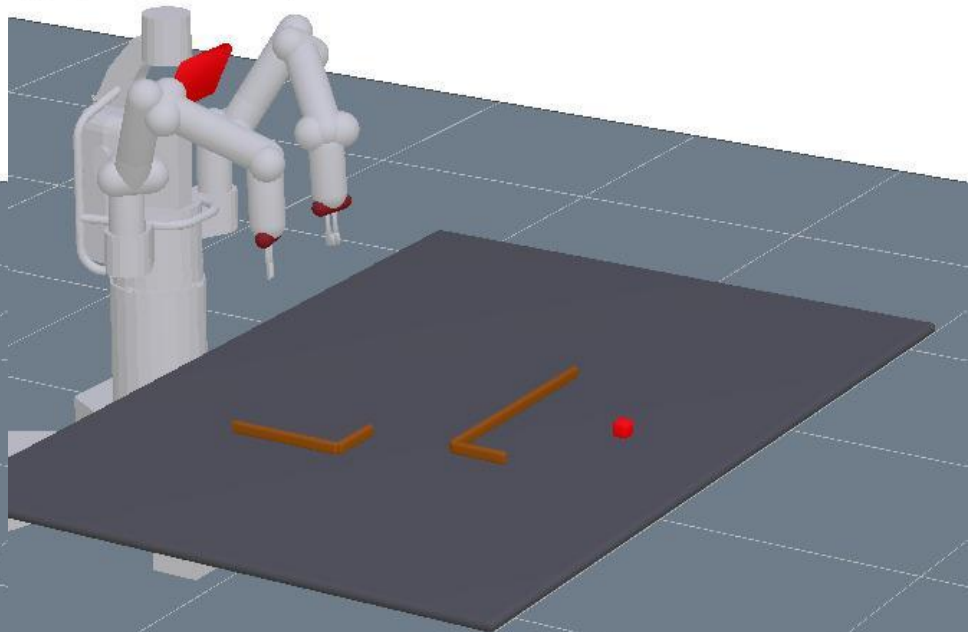(push stickTip redBall table1)
(grasp baxterR redBall)

time:4/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:5/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:5/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
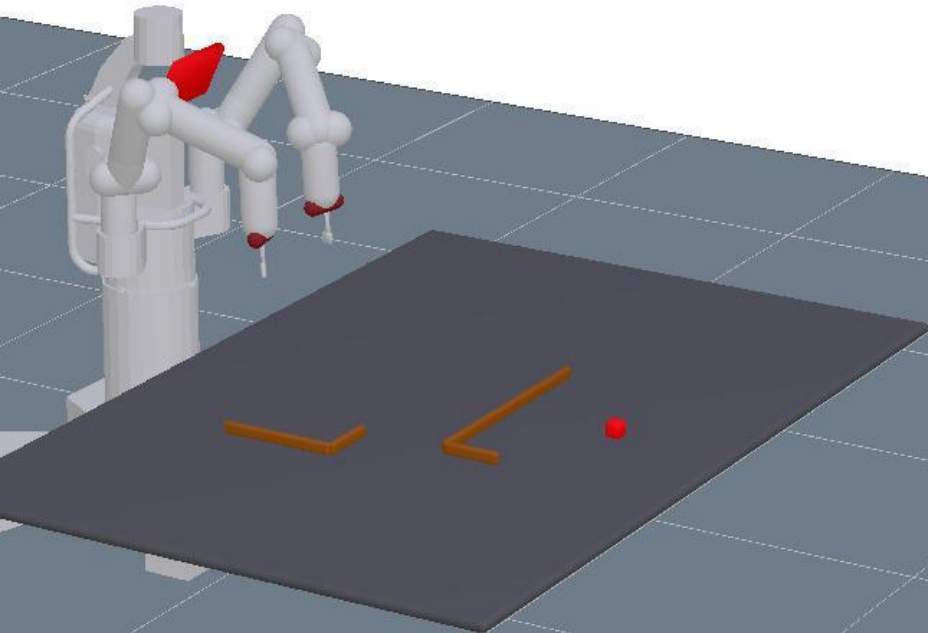(grasp baxterR redBall)

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time:6/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
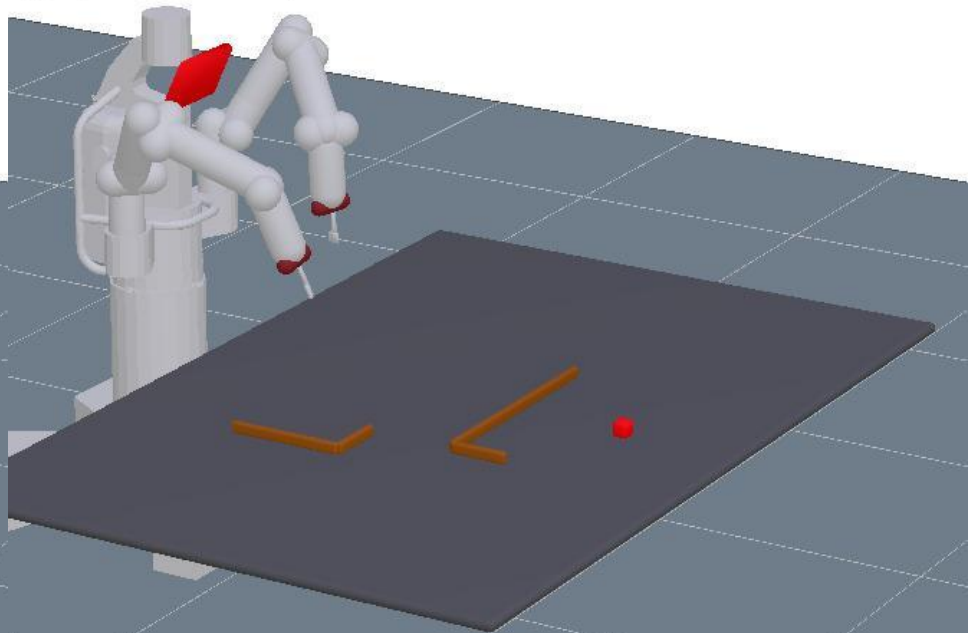(push stickTip redBall table1)
(grasp baxterR redBall)

time:6/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
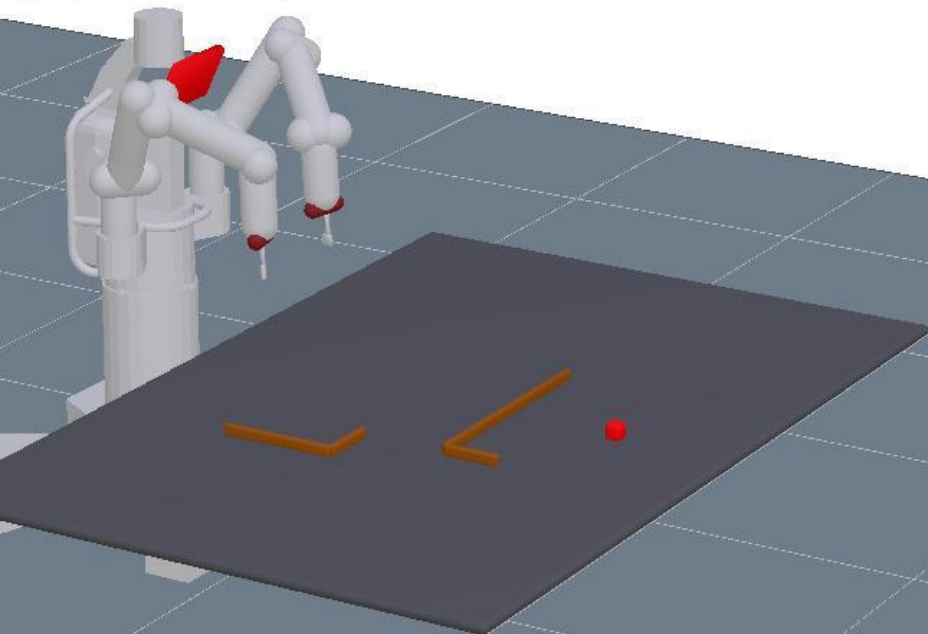(grasp baxterR redBall)

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time:7/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:7/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:8/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
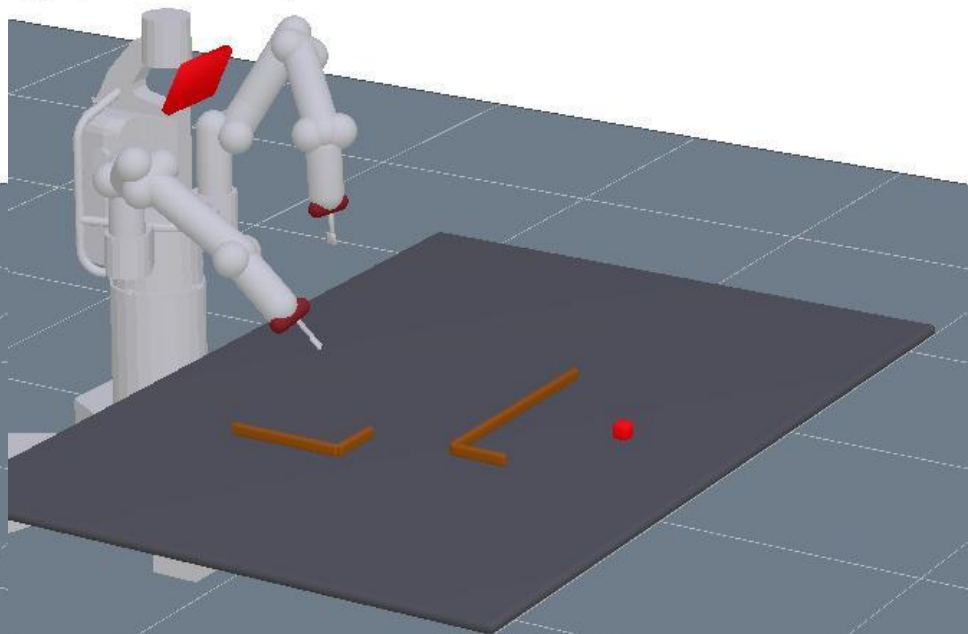(push stickTip redBall table1)
(grasp baxterR redBall)

time:8/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
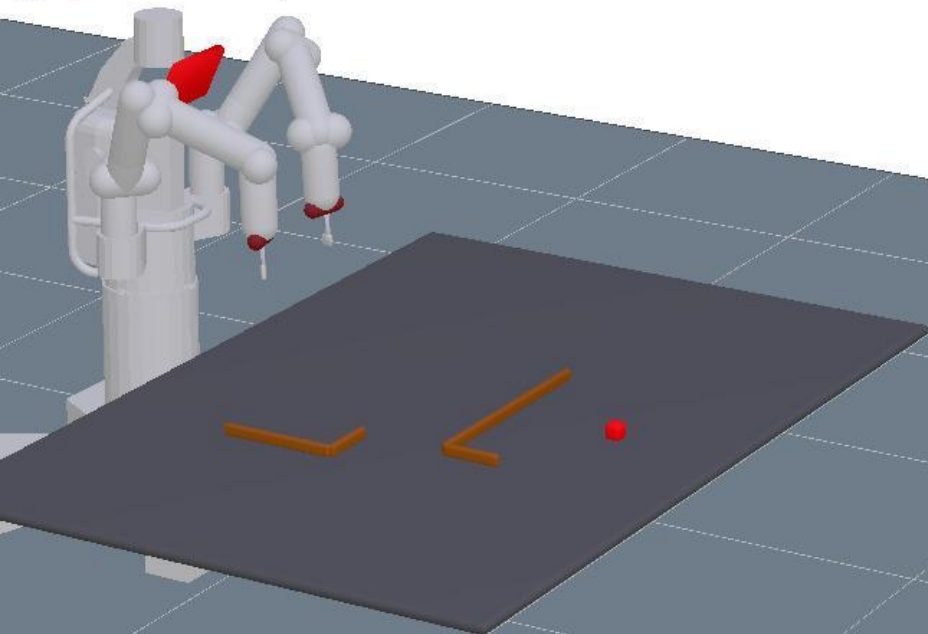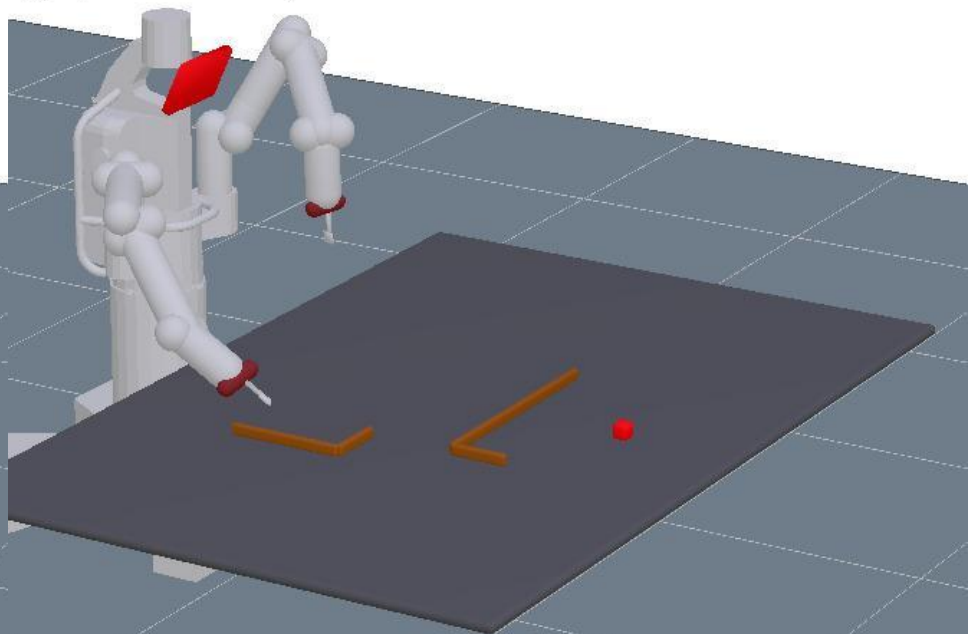(push stickTip redBall table1)
(grasp baxterR redBall)

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time:9/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)   StepsPerPhase:5
(place baxterR stick2 table1)   Newton Steps:0
(grasp baxterL stick)   mu:4
(push stickTip redBall table1)   nu:4
(grasp baxterR redBall)

time:9/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)   StepsPerPhase:5
(place baxterR stick2 table1)   Newton Steps:1000
(grasp baxterL stick)   mu:262144
(push stickTip redBall table1)   nu:262144
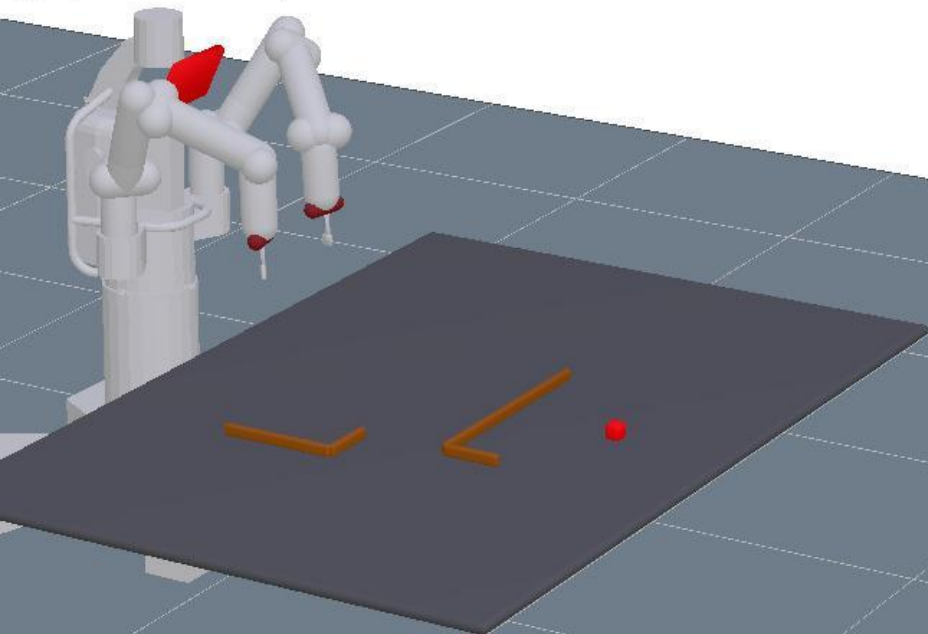(grasp baxterR redBall)

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time:10/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:10/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:11/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
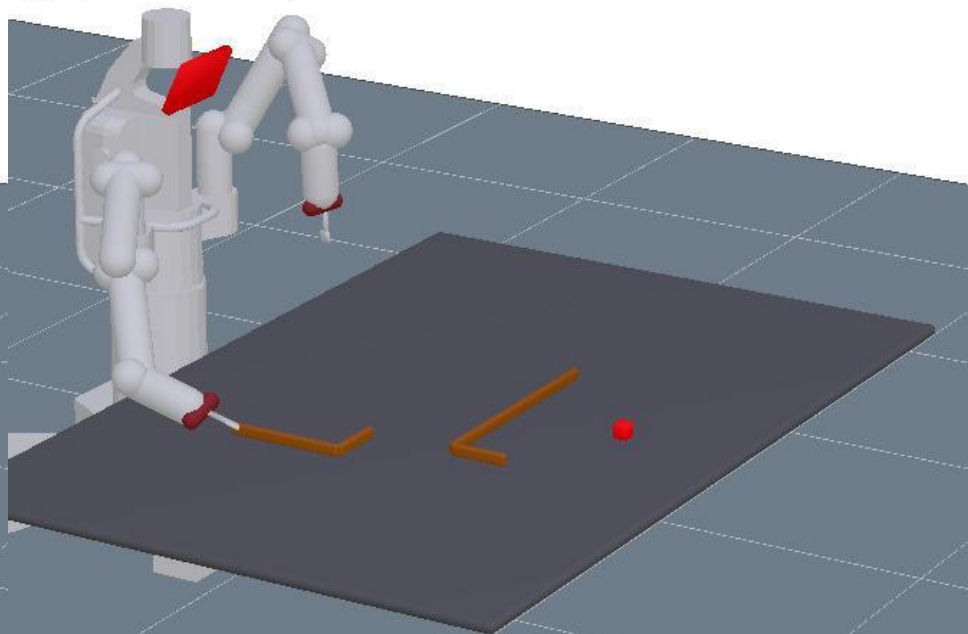(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:11/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)
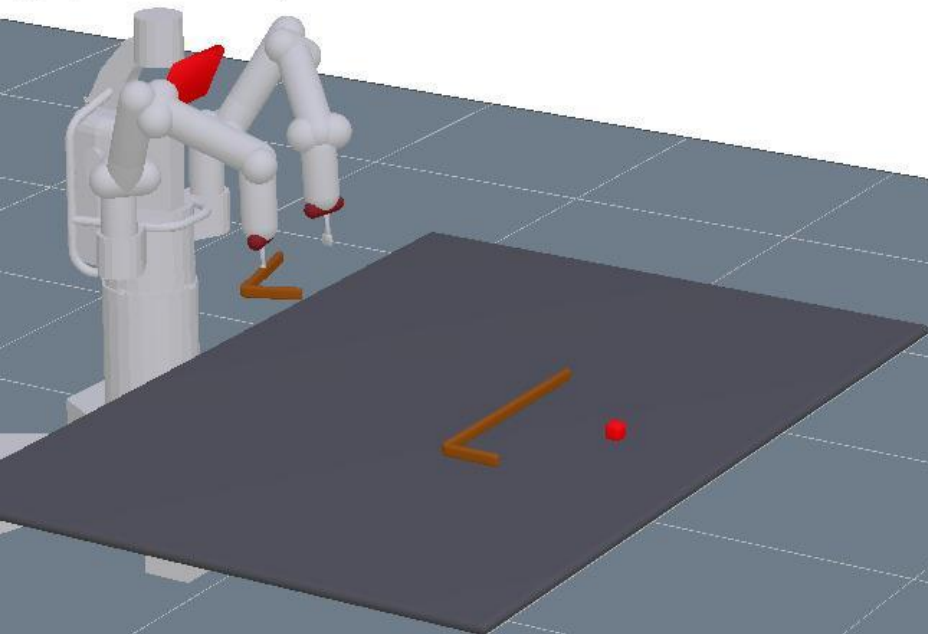
StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:12/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:12/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
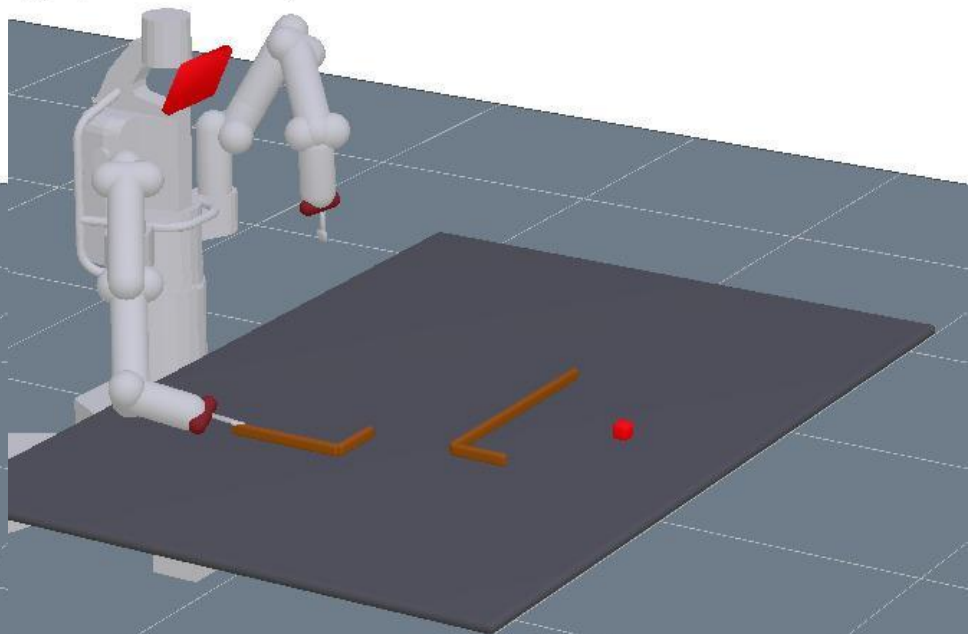(push stickTip redBall table1)
(grasp baxterR redBall)
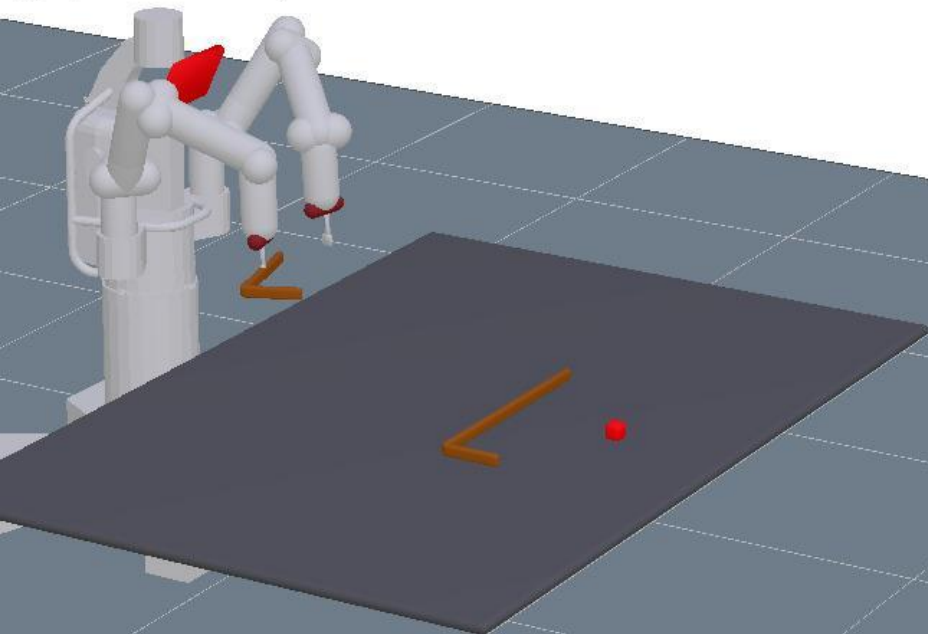
StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

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time:13/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:13/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

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(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:14/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:14/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

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time:15/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
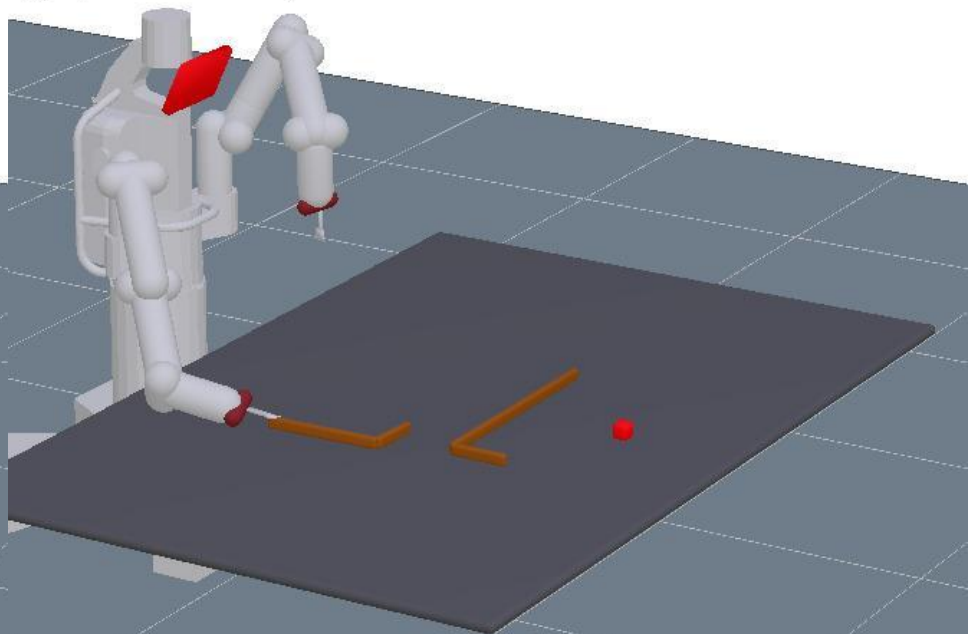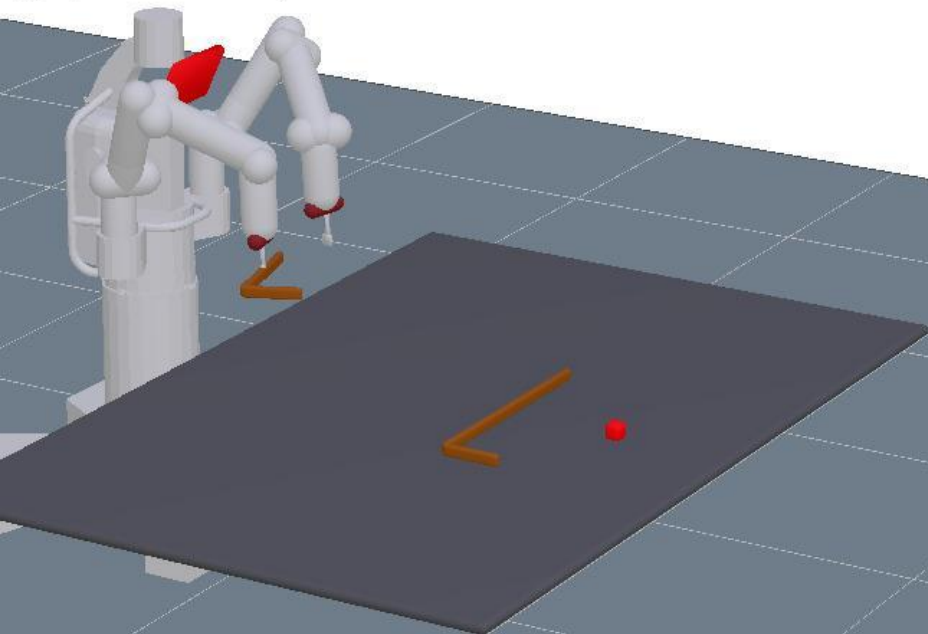(push stickTip redBall table1)
(grasp baxterR redBall)

time:15/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:16/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
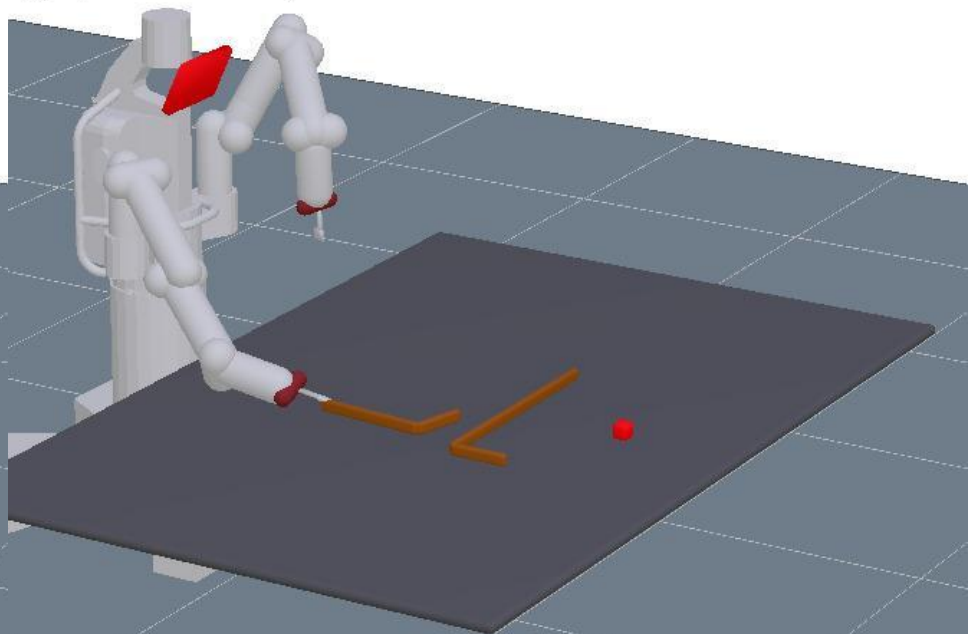(push stickTip redBall table1)
(grasp baxterR redBall)

time:16/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
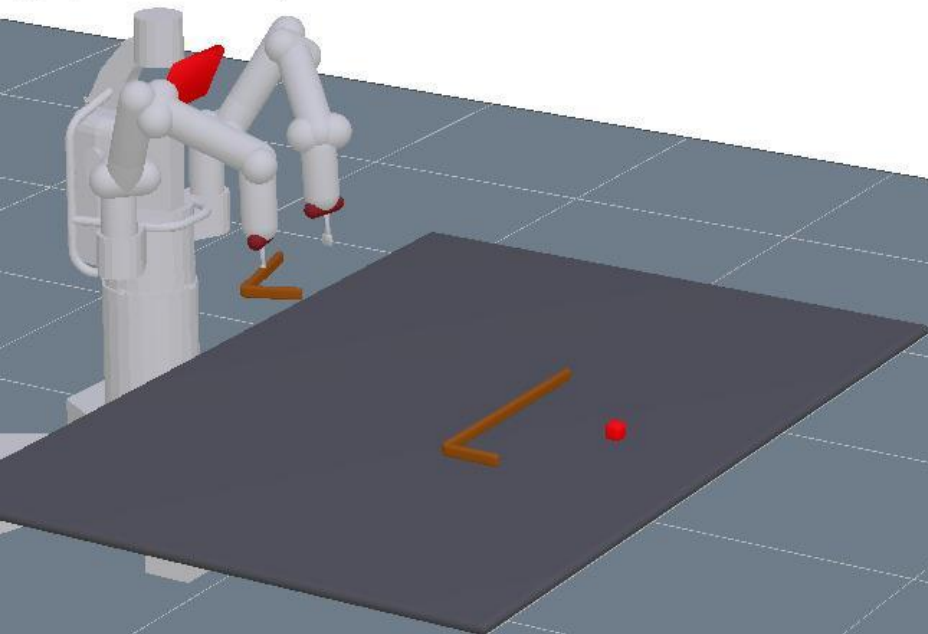(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:17/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351
_____

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:17/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116
_____

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
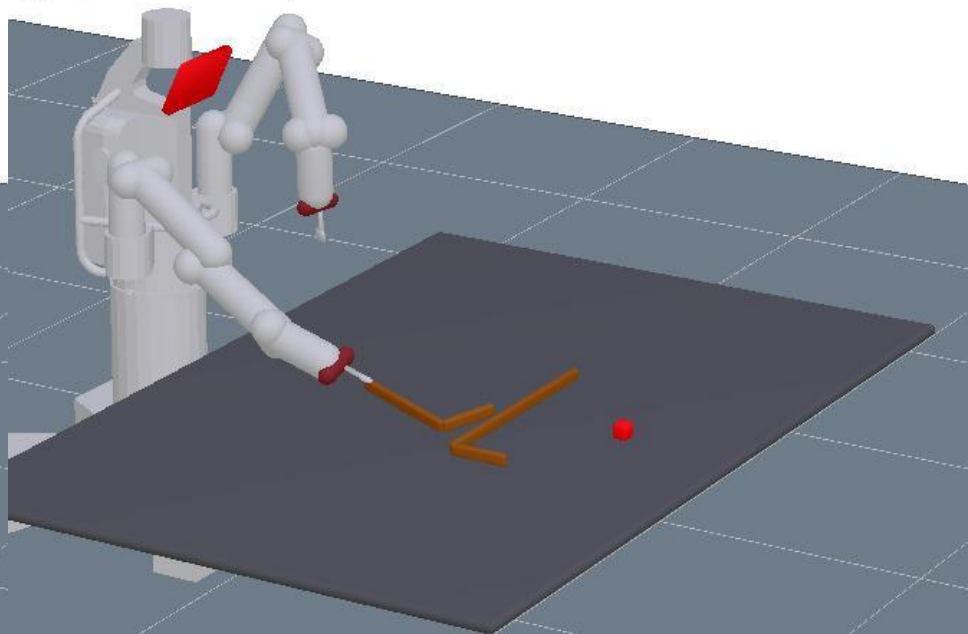(push stickTip redBall table1)
(grasp baxterR redBall)
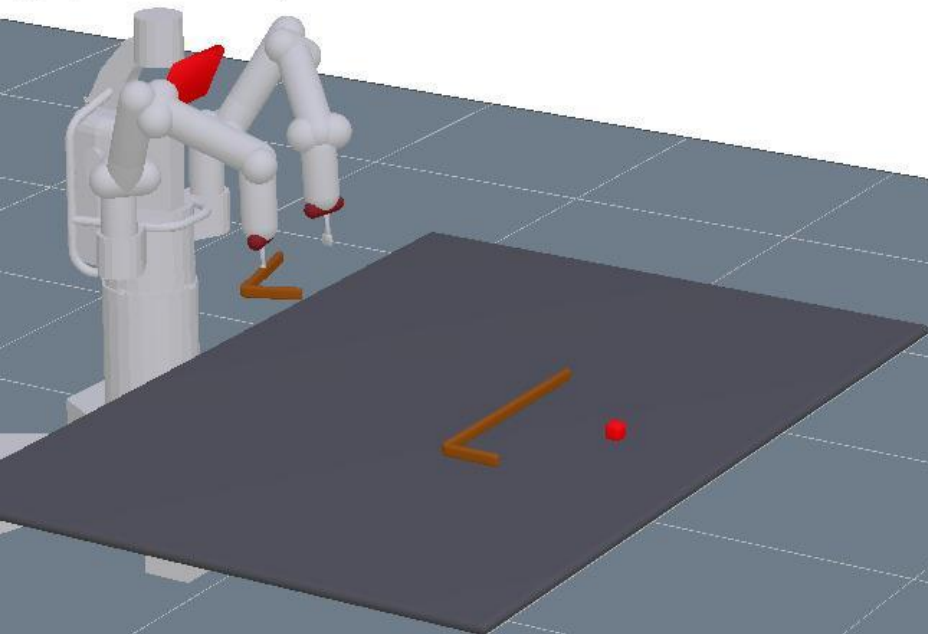
StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:18/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:18/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:19/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
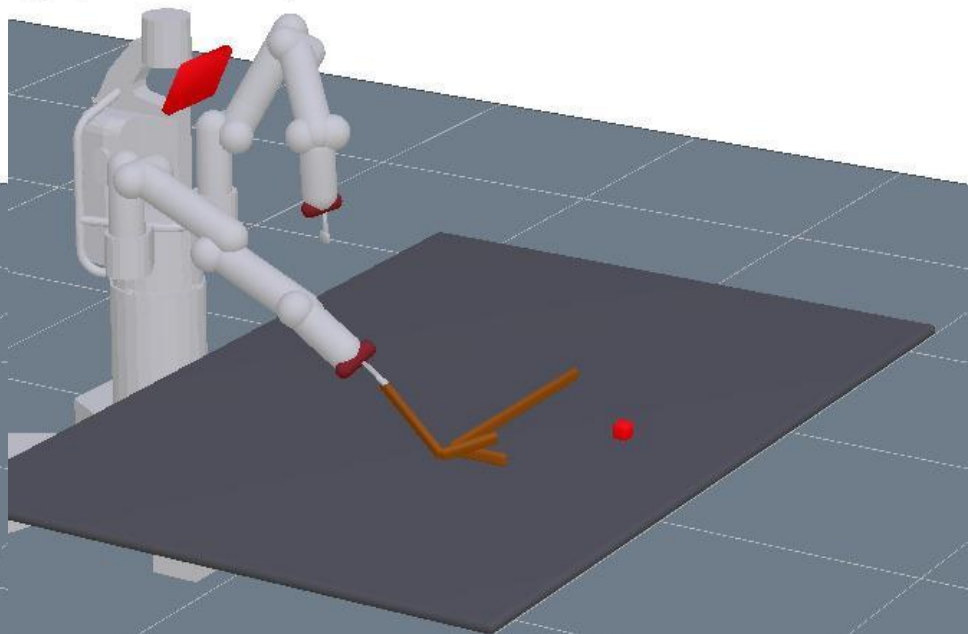(push stickTip redBall table1)
(grasp baxterR redBall)

time:19/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
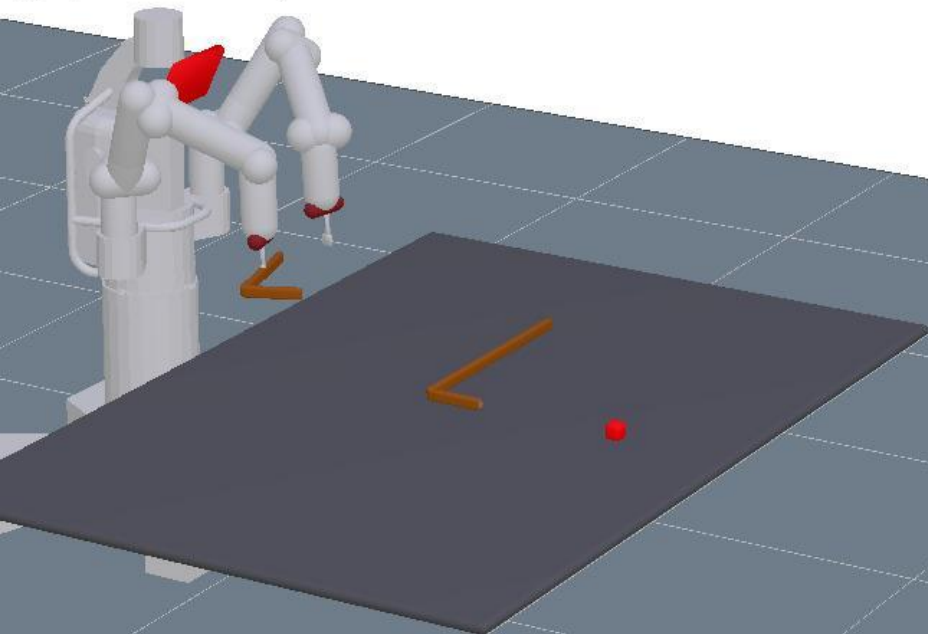(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:20/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:20/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:21/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
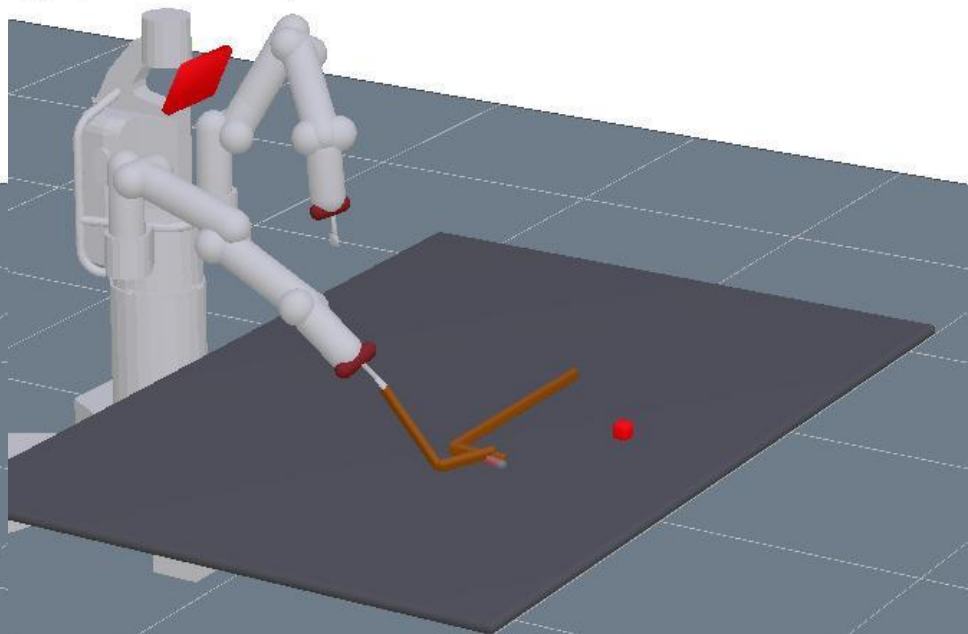(push stickTip redBall table1)
(grasp baxterR redBall)

time:21/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
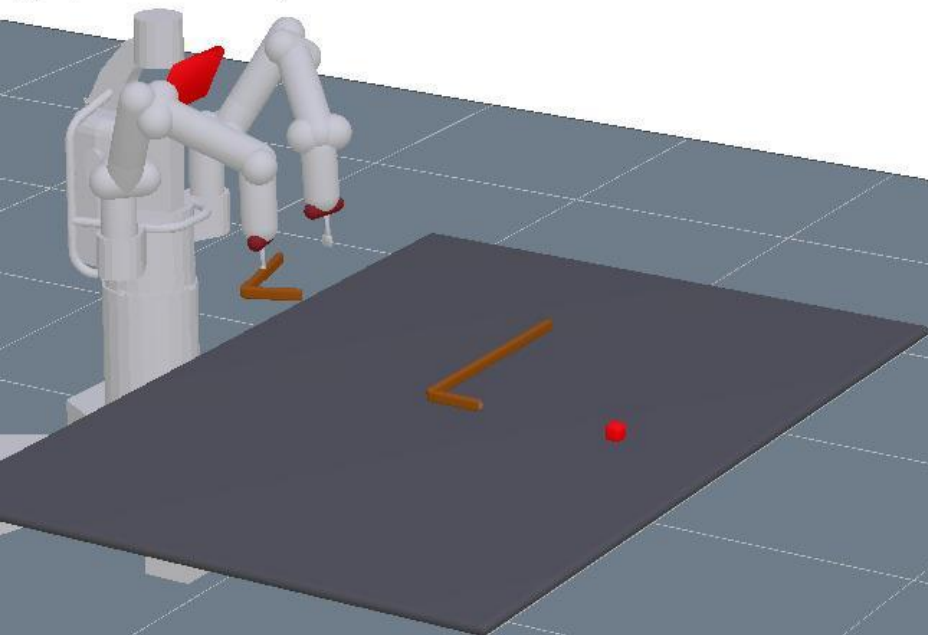(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:22/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:22/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:23/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
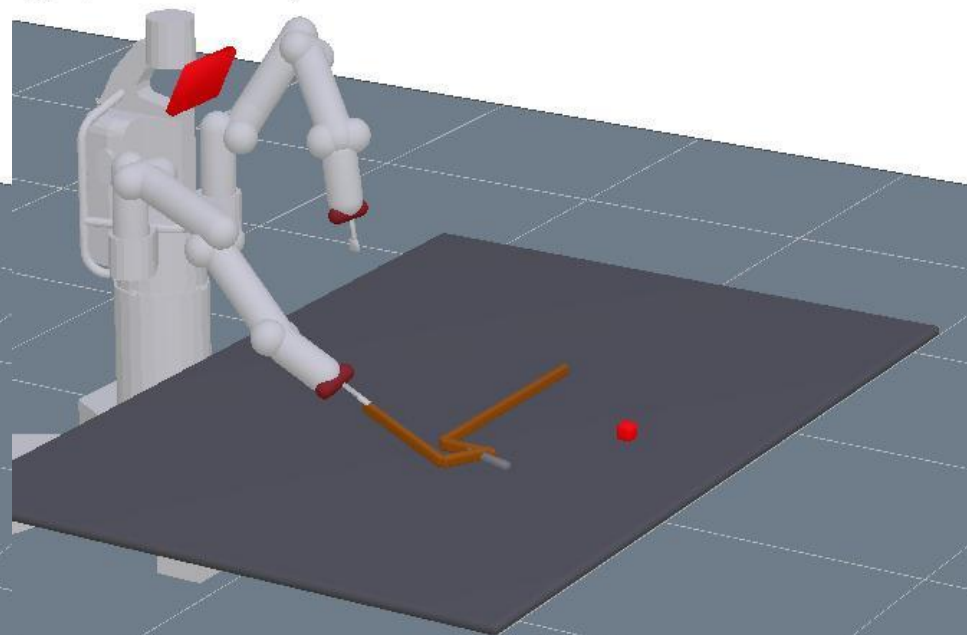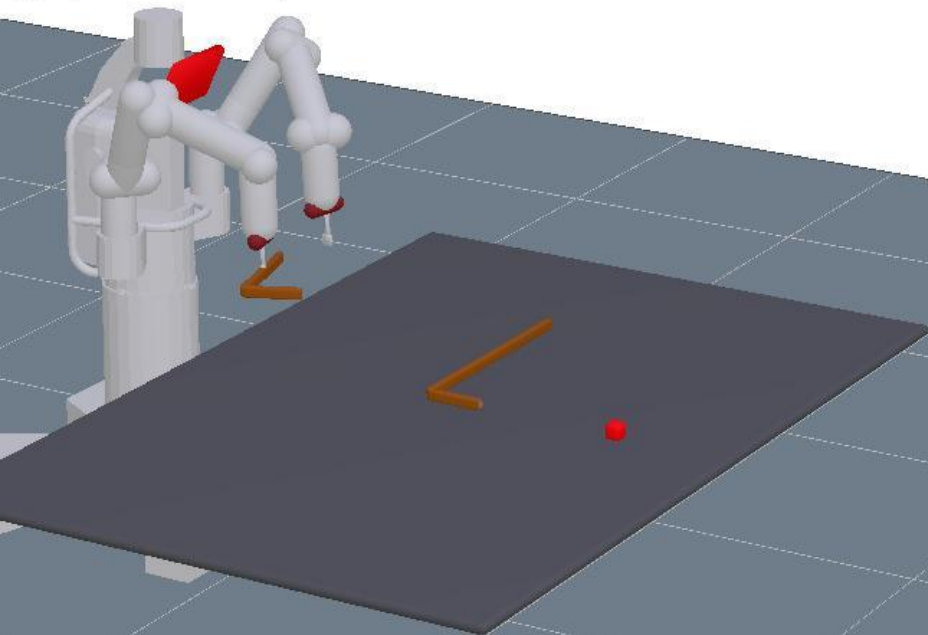(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:23/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:24/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
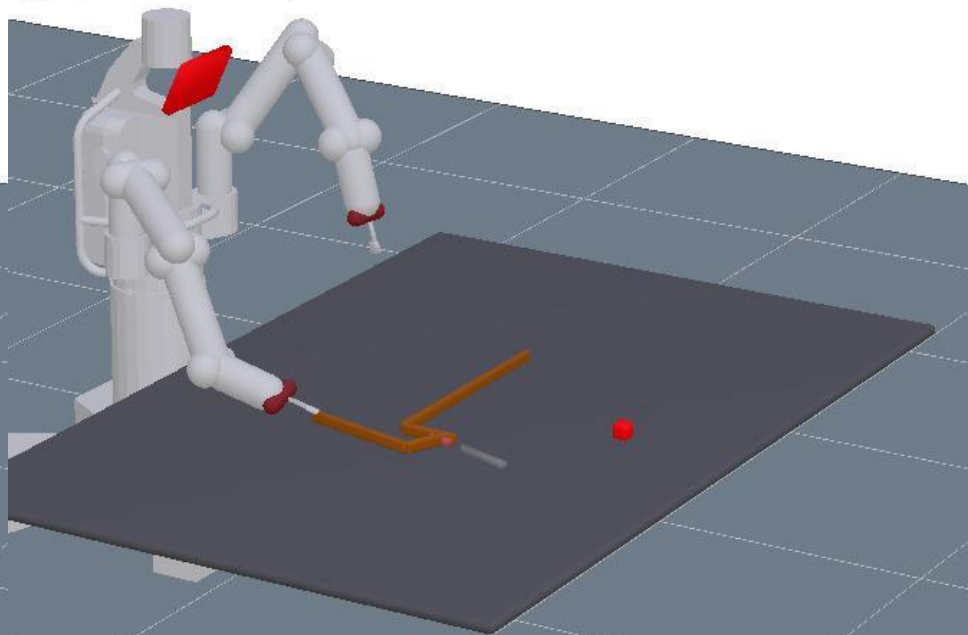(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:24/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:25/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:25/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
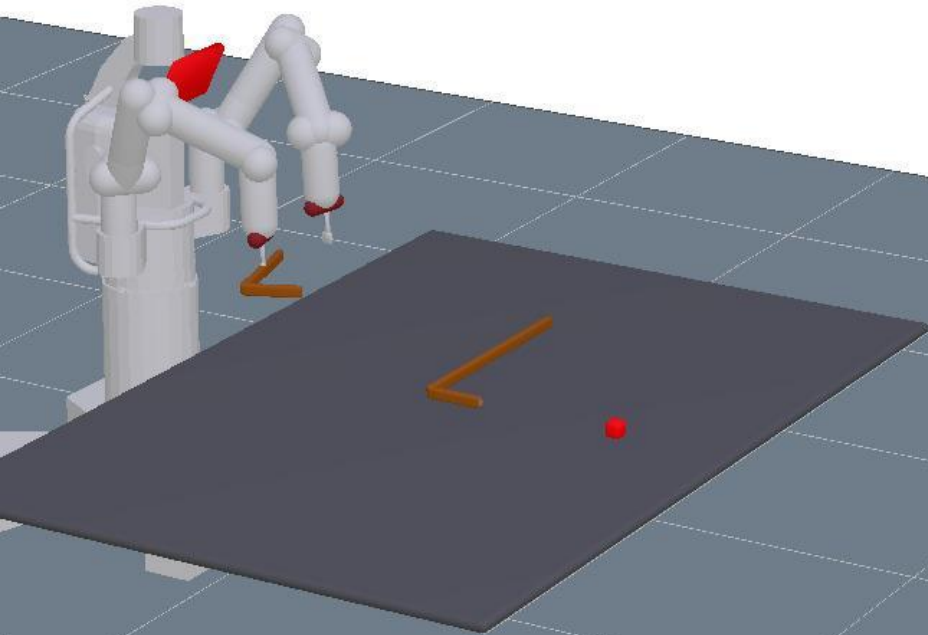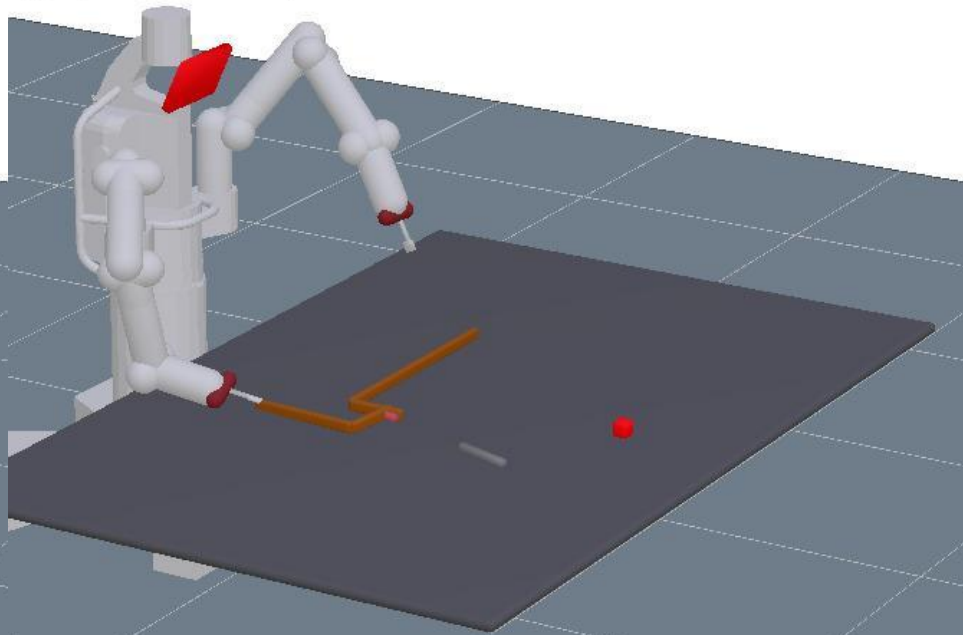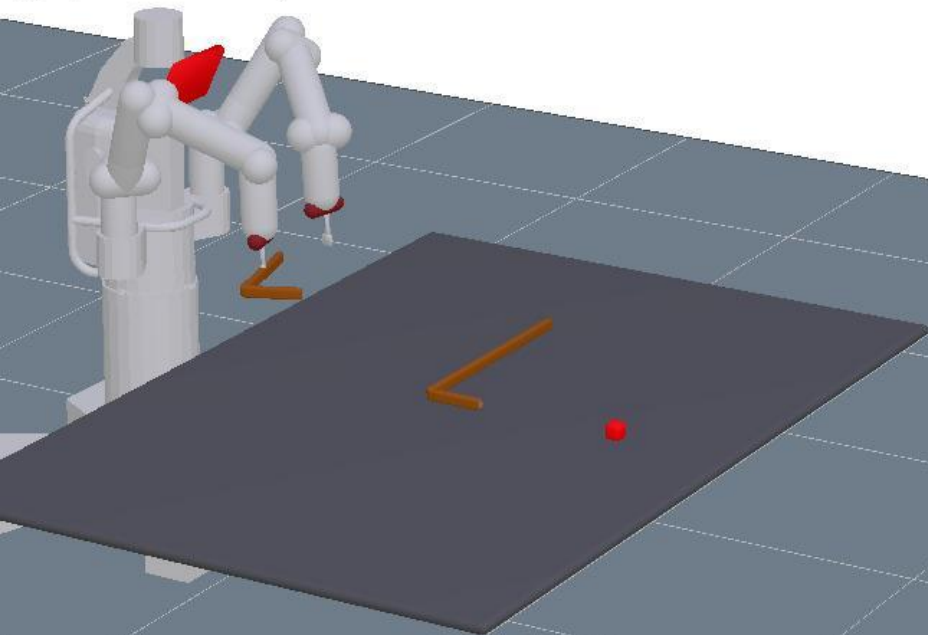Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:26/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:26/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:27/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:27/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:28/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
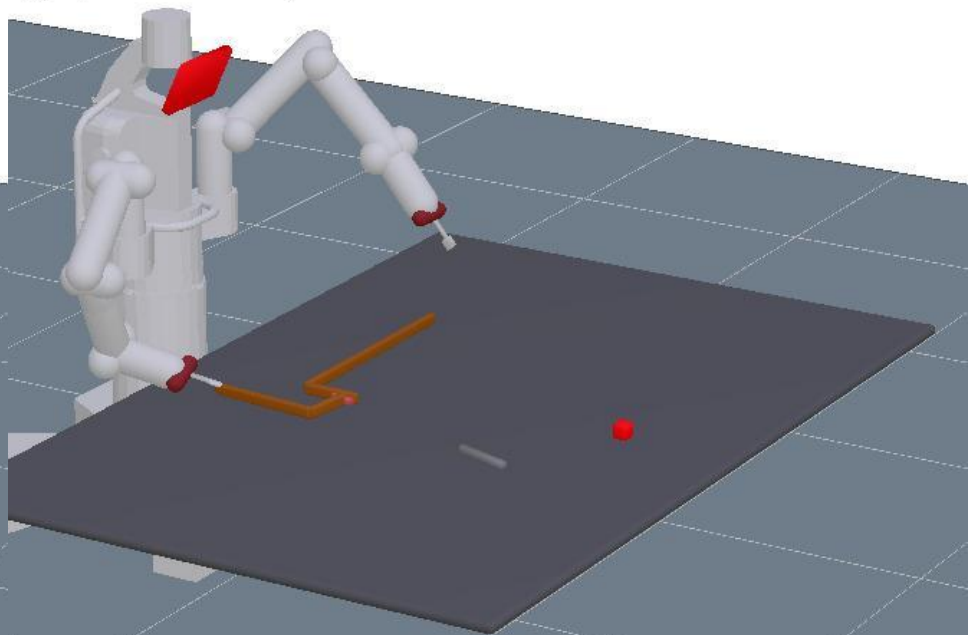(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:28/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
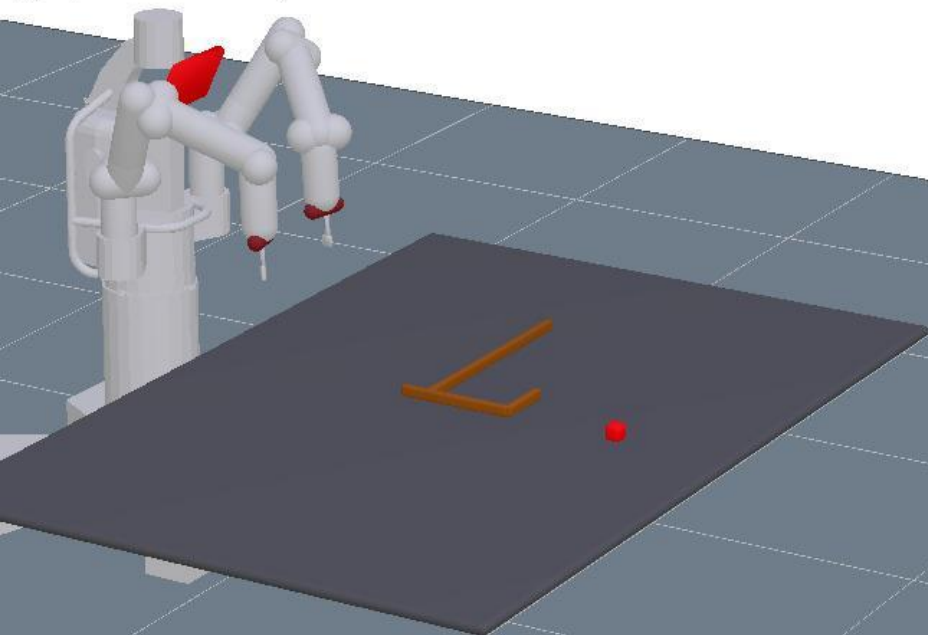Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:29/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:29/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
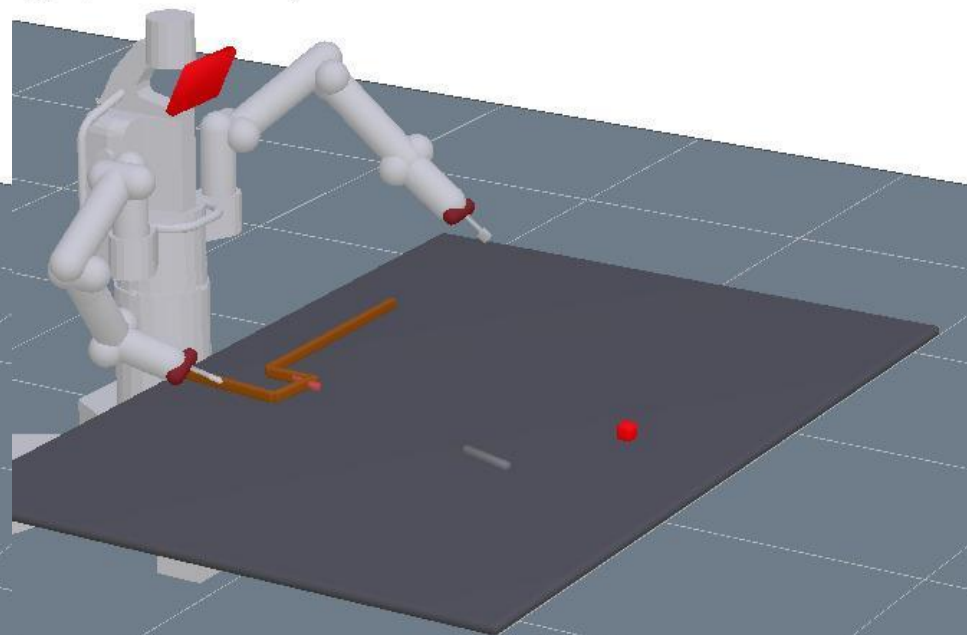(grasp baxterR redBall)
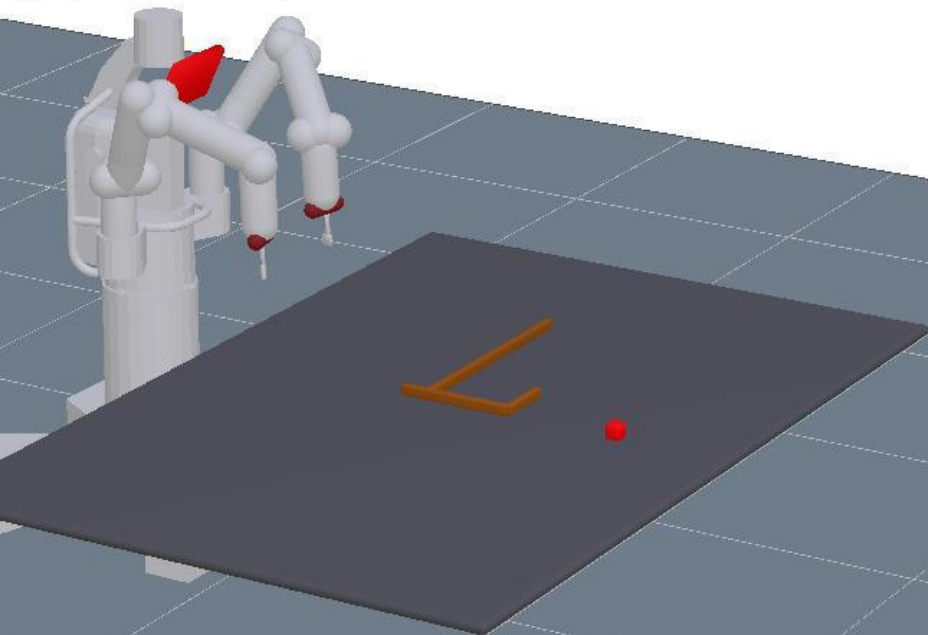
StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:30/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:30/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:31/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
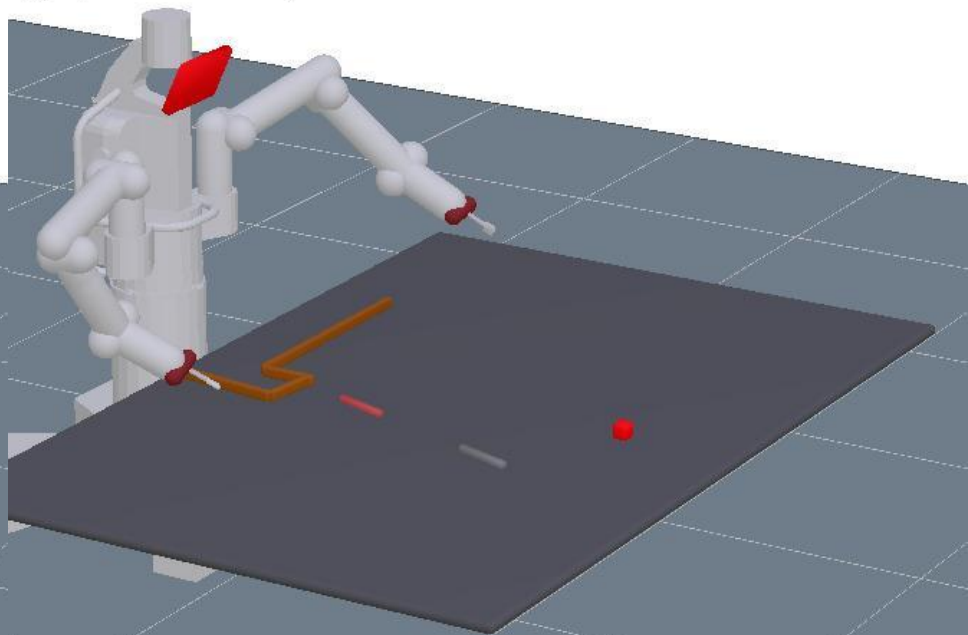(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:0
mu:4
nu:4

time:31/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)
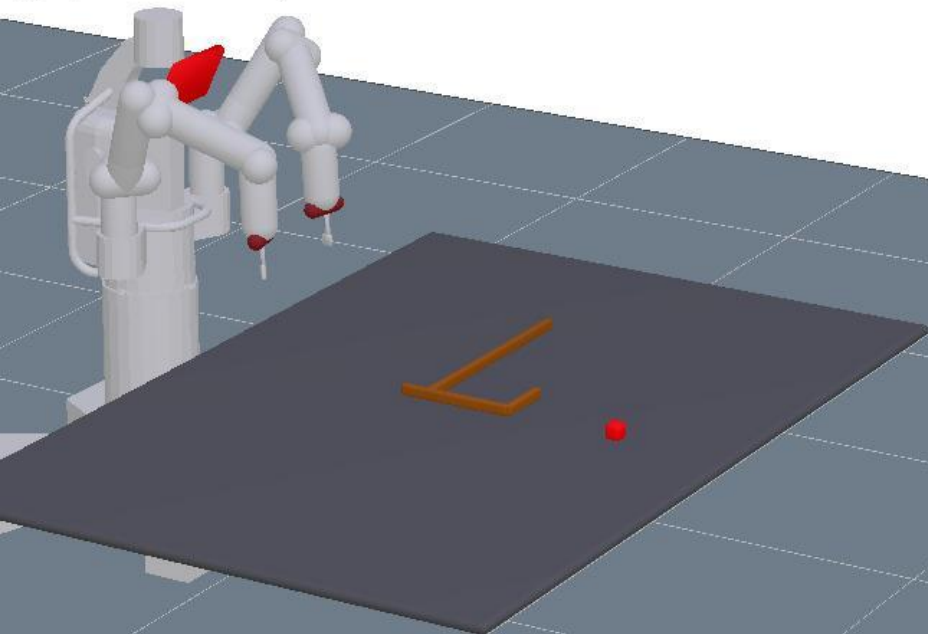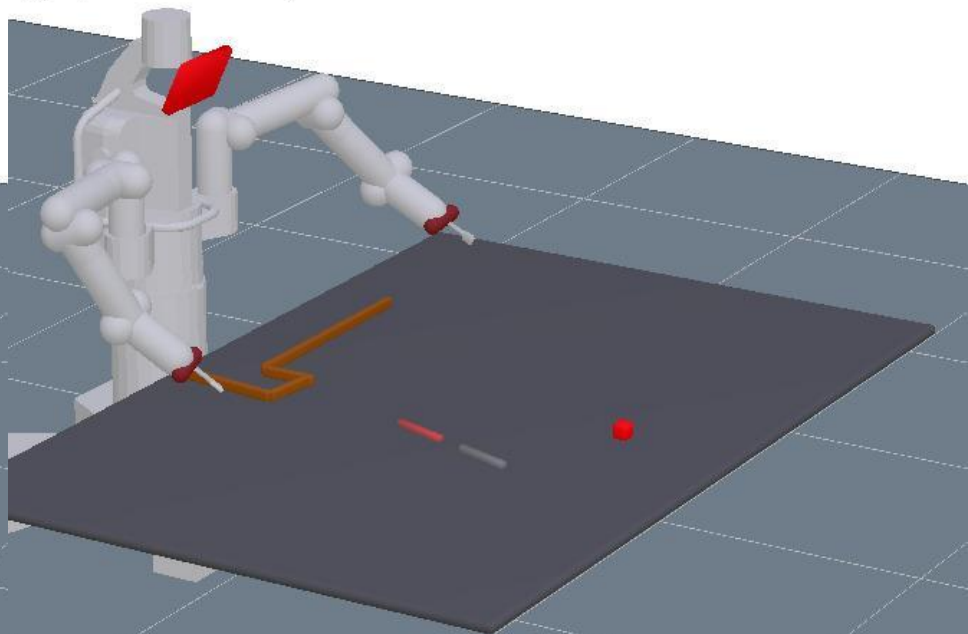
StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:32/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:32/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
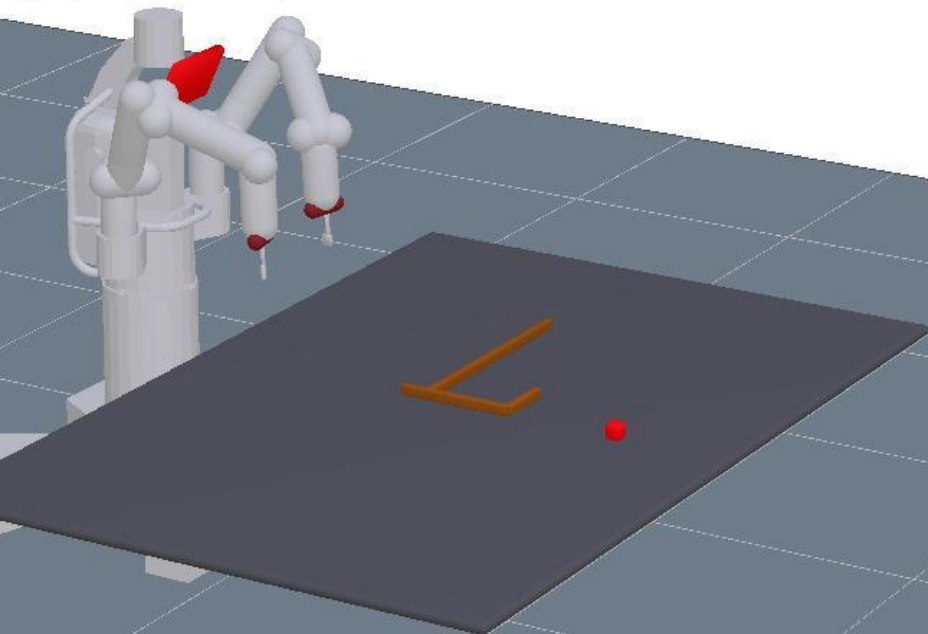(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

time:33/34 | cost for each level: 0.6 0 0 1237.41 | constraint violation:304.351

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:0
(place baxterR stick2 table1)   mu:4
(grasp baxterL stick)   nu:4
(push stickTip redBall table1)
(grasp baxterR redBall)

time:33/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)   StepsPerPhase:5
(push stickTip2 stickTip table1)   Newton Steps:1000
(place baxterR stick2 table1)   mu:262144
(grasp baxterL stick)   nu:262144
(push stickTip redBall table1)
(grasp baxterR redBall)

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

q(t_0)	q(t_1)	q(t_2)	q(t_3)	q(t_4)	q(t_5)	q(t_6)	q(t_7)	q(t_8)	q(t_9)	q(t_10)	q(t_11)	q(t_12)	q(t_13)	q(t_14)	q(t_15)	q(t_16)	q(t_17)	q(t_18)	q(t_19)	q(t_20)	q(t_21)	q(t_22)	q(t_23)	q(t_24)	q(t_25)	q(t_26)	q(t_27)	q(t_28)	q(t_29)	q(t_30)	q(t_31)	q(t_32)	q(t_33)
0,00	0,00	-0,00	-0,01	-0,01	-0,00	0,01	0,03	0,04	0,04	0,02	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75
0,08	0,00	0,00	-0,11	-0,21	-0,25	-0,19	0,03	0,30	0,55	0,69	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-0,08	-0,08	-0,08	-0,08	-0,09	-0,09	-0,09	-0,09	-0,09	-0,08	-0,07	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12
-1,00	-1,00	-0,78	-0,43	-0,00	0,40	0,68	0,71	0,61	0,47	0,35	-0,02	-0,09	-0,26	-0,53	-0,75	-0,61	-0,61	-0,61	-0,61	-0,61	-0,75	-0,75	-0,75	-0,75	-0,75	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
-1,00	-1,00	-1,00	-1,01	-1,02	-1,03	-1,04	-1,05	-1,06	-1,06	-1,05	0,68	0,51	0,19	-0,19	-0,53	-0,10	-0,10	-0,10	-0,10	-0,10	-0,28	-0,28	-0,28	-0,28	-0,28	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15
1,17	1,17	1,03	0,80	0,53	0,27	0,07	-0,00	-0,01	-0,01	-0,01	-0,06	-0,03	0,01	0,07	0,14	-0,00	-0,00	-0,00	-0,00	-0,00	-0,12	-0,12	-0,12	-0,12	-0,12	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-1,17	-1,17	-1,17	-1,18	-1,19	-1,20	-1,21	-1,22	-1,22	-1,21	-1,20	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	0,01	0,07	0,17	0,31	0,45	0,54	0,49	0,34	0,08	-0,21	-0,25	-0,20	-0,14
1,94	1,94	1,75	1,41	0,99	0,55	0,19	0,00	-0,07	-0,06	0,01	0,25	0,23	0,29	0,46	0,57	-0,28	-0,28	-0,28	-0,28	-0,28	-0,31	-0,19	-0,08	0,03	0,14	0,25	0,37	0,50	0,65	0,80	0,94	1,01	1,07
1,94	1,94	1,94	1,95	1,96	1,97	1,99	2,00	2,01	2,02	2,02	-1,03	-0,99	-0,92	-0,83	-0,71	-0,12	-0,12	-0,12	-0,12	-0,12	0,42	0,11	-0,29	-0,64	-0,86	-0,80	-0,48	-0,05	0,43	0,91	1,11	1,27	1,42
-0,67	-0,67	-0,81	-1,04	-1,28	-1,47	-1,55	-1,41	-1,15	-0,83	-0,54	0,01	0,12	0,24	0,18	-0,00	-0,94	-0,60	-0,30	-0,12	-0,03	-0,68	-0,80	-0,87	-0,89	-0,85	0,28	0,28	0,28	0,28	0,28	0,21	0,37	0,50
0,67	0,67	0,67	0,66	0,65	0,64	0,63	0,62	0,62	0,63	0,66	-1,16	-1,11	-1,03	-0,92	-0,77	-0,68	-0,71	-0,65	-0,55	-0,44	0,45	0,51	0,52	0,47	0,38	-0,76	-0,62	-0,44	-0,23	-0,00	-0,12	-0,14	-0,17
1,02	1,02	0,70	0,17	-0,41	-0,92	-1,19	-1,04	-0,66	-0,22	0,11	0,16	0,49	0,90	1,31	1,54	0,23	0,33	0,43	0,51	0,52	0,88	0,99	1,06	1,10	1,11	0,26	0,14	0,06	-0,01	-0,10	0,84	0,78	0,72
1,02	1,02	1,03	1,04	1,06	1,08	1,10	1,11	1,11	1,10	1,06	2,01	1,98	1,92	1,83	1,70	0,47	0,26	-0,00	-0,26	-0,49	0,18	0,04	-0,20	-0,48	-0,74	1,10	1,07	1,02	0,96	0,90	-0,81	-0,82	-0,85
0,50	0,50	0,56	0,67	0,81	0,97	1,11	1,20	1,26	1,26	1,21	-0,42	-0,61	-0,88	-1,17	-1,40	-0,56	-0,37	-0,16	0,07	0,28	2,07	2,05	2,01	1,94	1,84	-0,94	-1,02	-1,02	-0,96	-0,85	0,76	0,61	0,48
-0,50	-0,50	-0,50	-0,50	-0,50	-0,49	-0,49	-0,49	-0,48	-0,48	-0,47	0,70	0,76	0,85	0,97	1,13	0,02	0,16	0,36	0,55	0,73	0,20	0,12	0,11	0,12	0,12	1,71	1,56	1,37	1,17	0,95	1,64	1,89	2,12
						0,03	0,03	0,03	0,03	0,03	0,14	-0,31	-0,88	-1,30	-1,44	-0,60	-0,40	-0,19	0,01	0,15	-0,93	-0,83	-0,76	-0,71	-0,69	0,14	0,36	0,69	1,06	1,40	-0,80	-0,83	-0,85
						0,04	0,04	0,04	0,04	0,04	0,99	0,88	0,72	0,50	0,22	1,73	1,86	1,96	2,02	2,06	2,14	1,91	1,54	1,10	0,64	-0,68	-0,69	-0,71	-0,73	-0,77	0,10	0,11	0,11
						-0,17	-0,17	-0,18	-0,18	-0,18	1,05	0,74	0,43	0,13	-0,16	1,52	1,29	1,02	0,72	0,43	0,46	0,68	0,82	0,90	0,91	0,26	0,10	0,03	0,03	0,07	0,23	0,12	0,03
						0,52	0,52	0,52	0,52	0,52	-0,46	-0,46	-0,46	-0,46	-0,47	-1,47	-1,42	-1,32	-1,18	-1,05	-1,56	-1,21	-0,68	-0,15	0,23	0,88	0,80	0,69	0,54	0,38	1,26	1,12	0,98
						-0,56	-0,56	-0,56	-0,56	-0,56	0,02	0,02	0,02	0,02	0,02	1,32	1,53	1,76	1,97	2,12	0,23	0,32	0,39	0,44	0,48	0,53	0,81	1,05	1,25	1,38	0,52	0,52	0,51
						0,27	0,27	0,27	0,26	0,26	0,04	0,04	0,04	0,04	0,04	-1,27	-0,94	-0,55	-0,16	0,18	-0,73	-0,77	-0,80	-0,81	-0,80	0,50	0,51	0,52	0,52	0,52	-0,13	-0,07	-0,02
						0,57	0,57	0,57	0,57	0,57	-0,19	-0,19	-0,19	-0,19	-0,19	-0,11	-0,50	-0,90	-1,27	-1,53	0,02	0,02	0,02	0,02	0,02	-0,76	-0,62	-0,46	-0,31	-0,18	0,02	0,02	0,02
											0,52	0,52	0,52	0,52	0,52	-0,26	-0,23	-0,13	-0,01	0,11	0,04	0,04	0,04	0,04	0,04	0,02	0,02	0,02	0,02	0,02	0,04	0,04	0,04
											-0,56	-0,56	-0,56	-0,56	-0,56	-0,49	-0,52	-0,56	-0,61	-0,67	-0,19	-0,19	-0,19	-0,19	-0,19	0,04	0,04	0,04	0,04	0,04	-0,19	-0,19	-0,19
											0,26	0,26	0,26	0,26	0,26	0,02	0,02	0,02	0,02	0,02	0,23	0,23	0,23	0,23	0,23	-0,19	-0,19	-0,19	-0,19	-0,19	-0,00	-0,00	-0,00
											0,57	0,57	0,57	0,57	0,57	0,04	0,04	0,04	0,04	0,04	0,16	0,16	0,16	0,16	0,16	0,23	0,23	0,23	0,23	0,23	0,00	0,00	0,00
																-0,19	-0,19	-0,19	-0,19	-0,19	-0,24	-0,24	-0,24	-0,24	-0,24	0,16	0,16	0,16	0,16	0,16	-0,02	-0,02	-0,02
																					0,80	0,80	0,80	0,80	0,80	-0,24	-0,24	-0,24	-0,24	-0,24	0,23	0,23	0,23
																					-0,43	-429,00	-0,43	-0,43	-0,43	0,80	0,80	0,80	0,80	0,80	0,16	0,16	0,16
																					0,18	0,18	0,18	0,18	0,18	-0,43	-0,43	-0,43	-0,43	-0,43	-0,24	-0,24	-0,24
																					0,38	0,38	0,38	0,38	0,38	0,18	0,18	0,18	0,18	0,18	0,67	0,67	0,67
																										0,36	0,36	0,36	0,36	0,36	-0,34	-0,34	-0,34
																															-0,06	-0,06	-0,06
																															0,66	0,66	0,66
																															0,80	0,80	0,80
																															-0,43	-0,43	-0,43
																															0,18	0,18	0,18
																															0,38	0,38	0,38

time:9/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
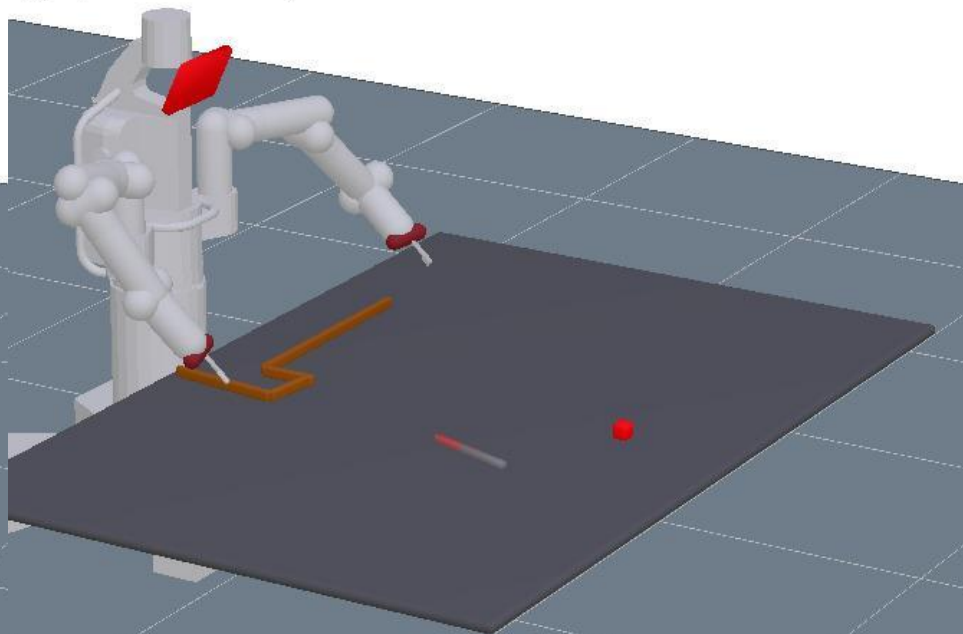(push stickTip redBall table1)
(grasp baxterR redBall)
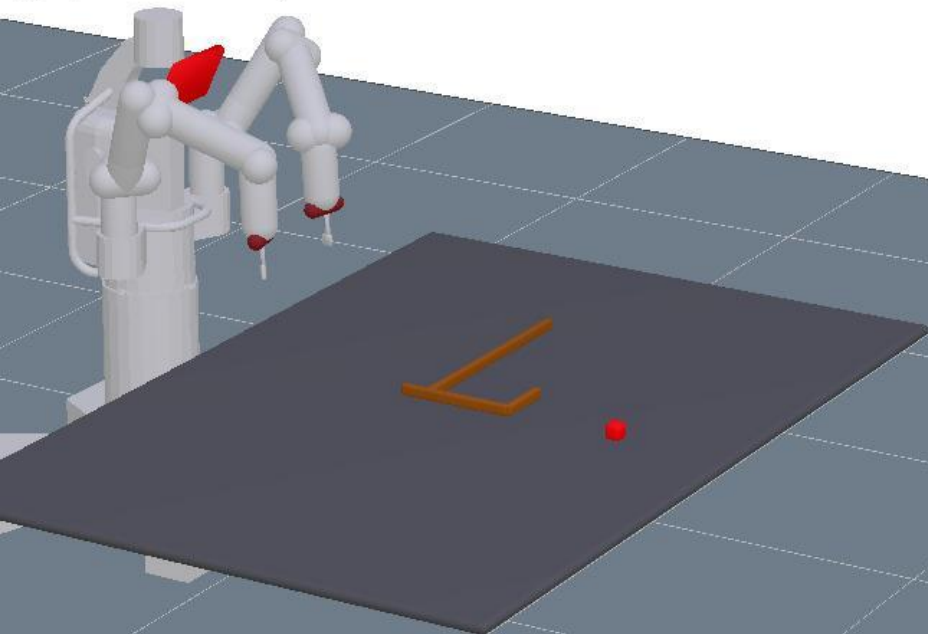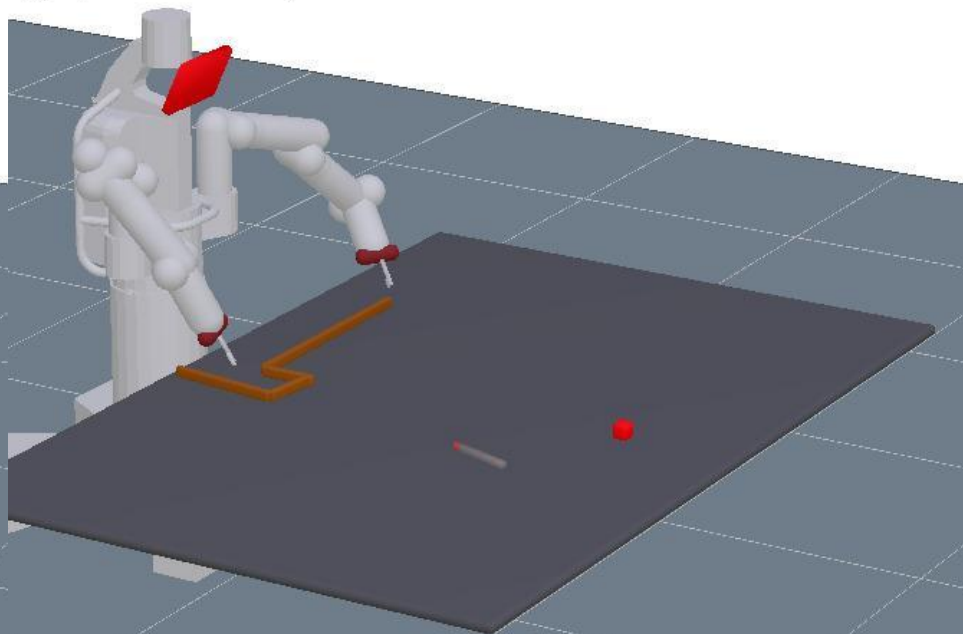
StepsPerPhase:5
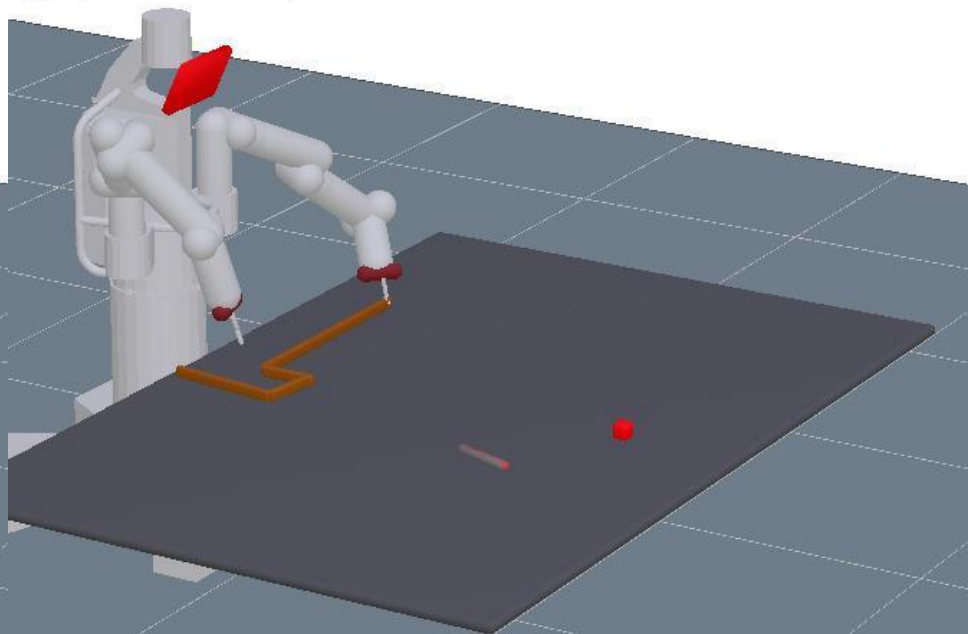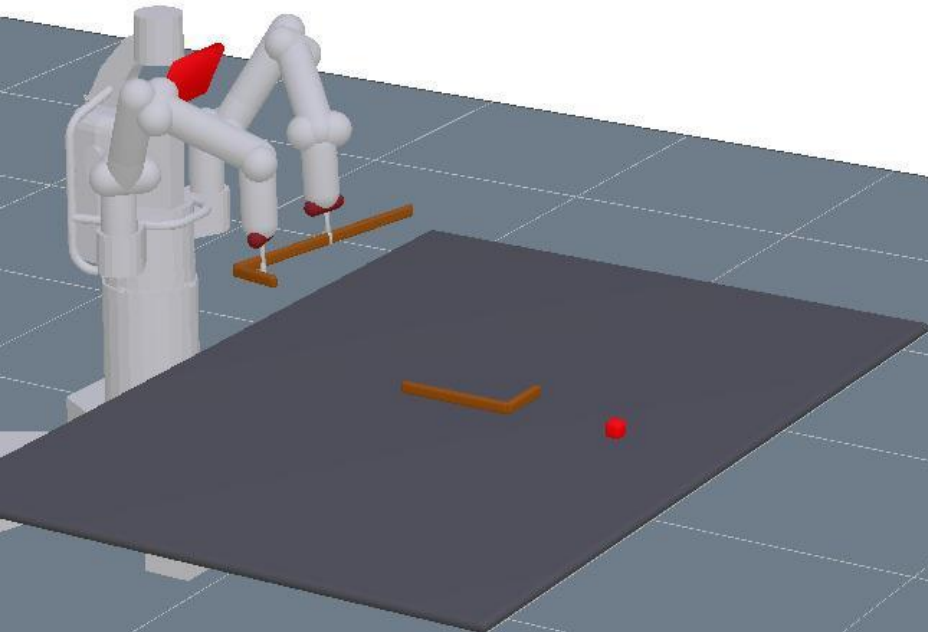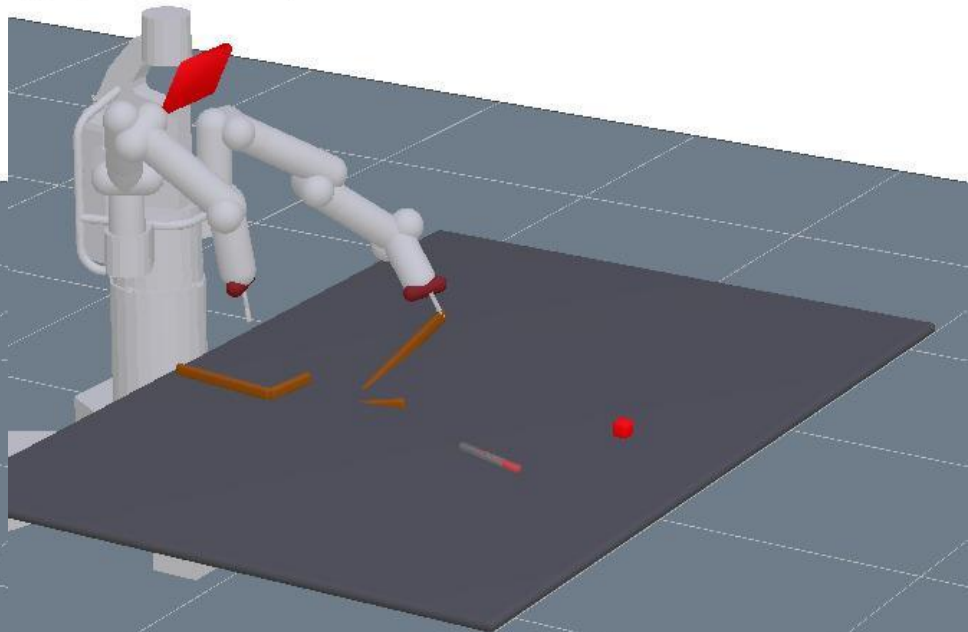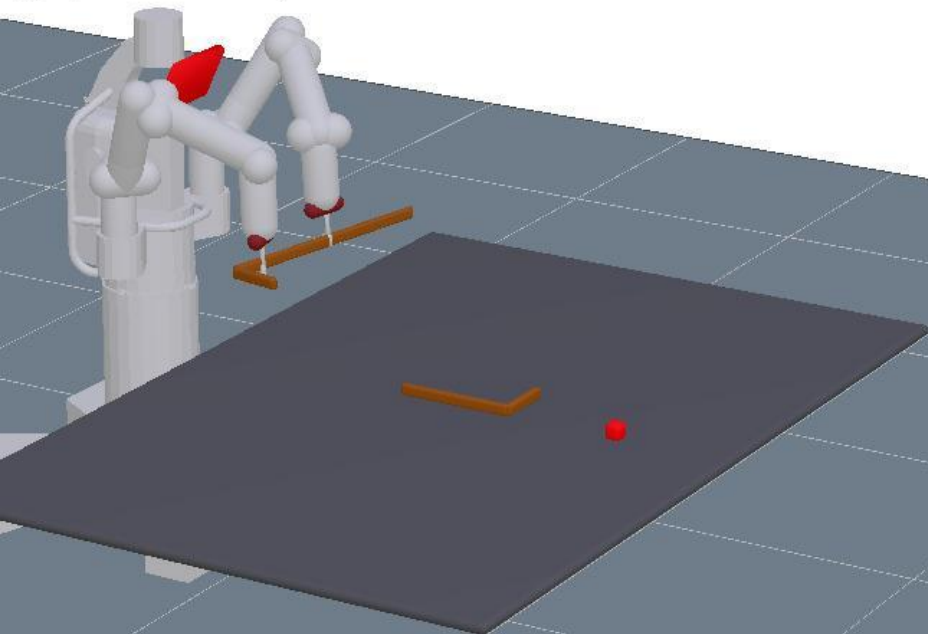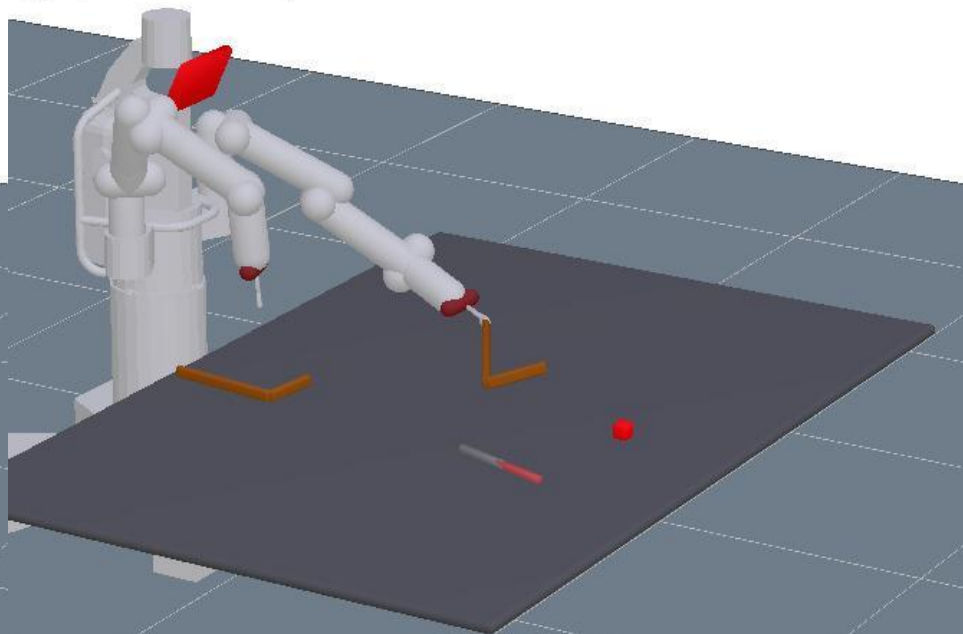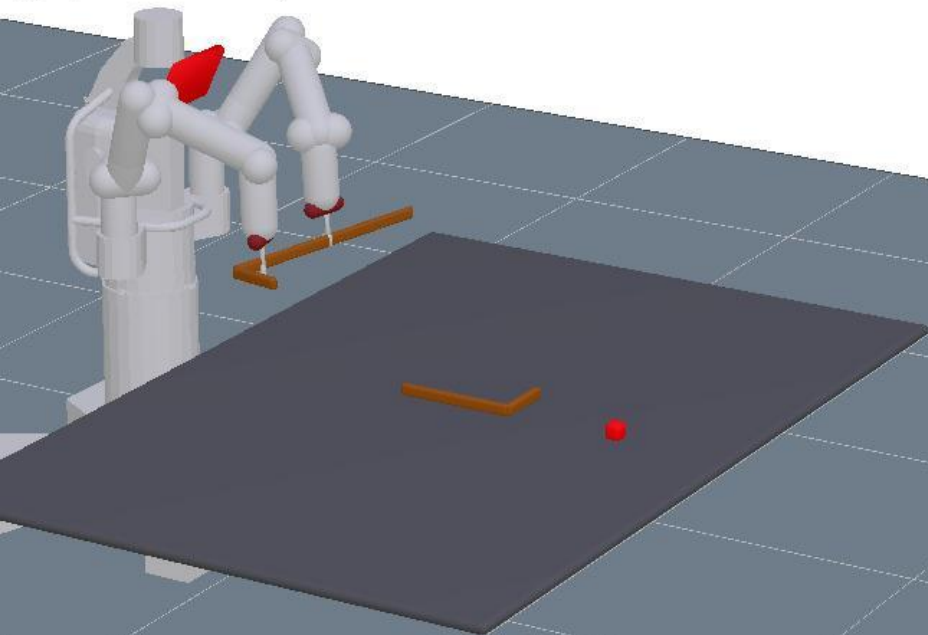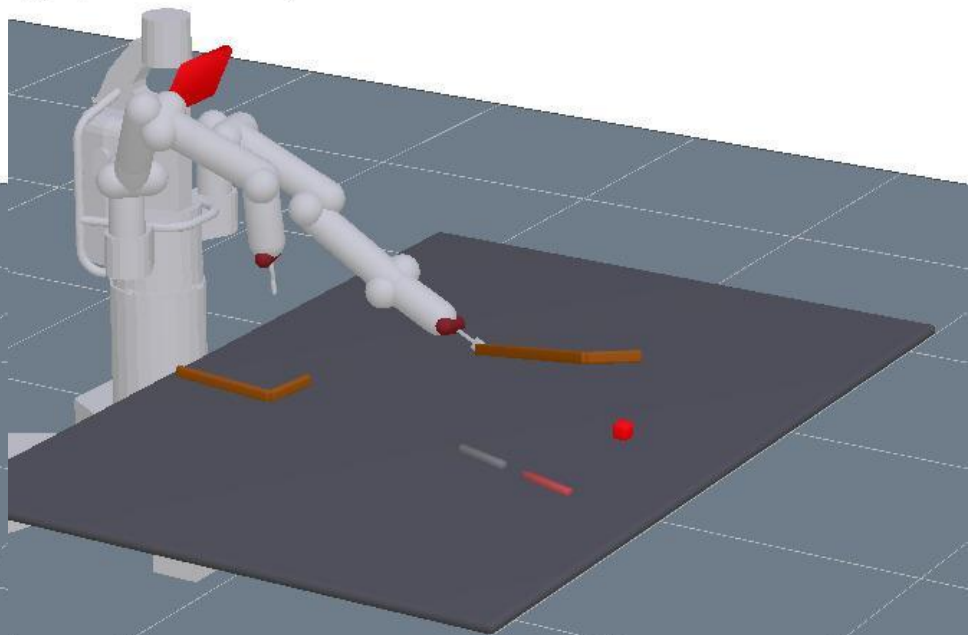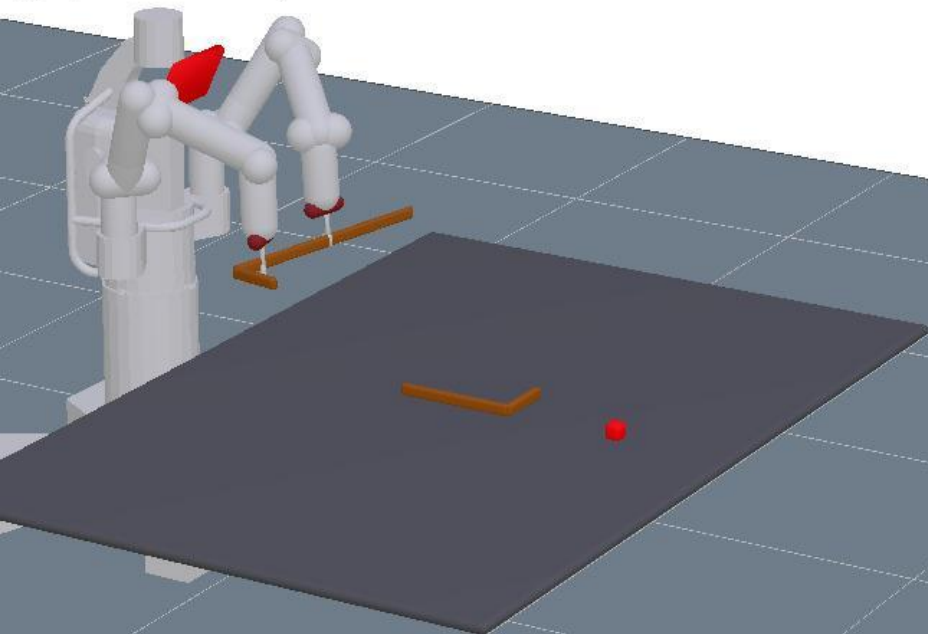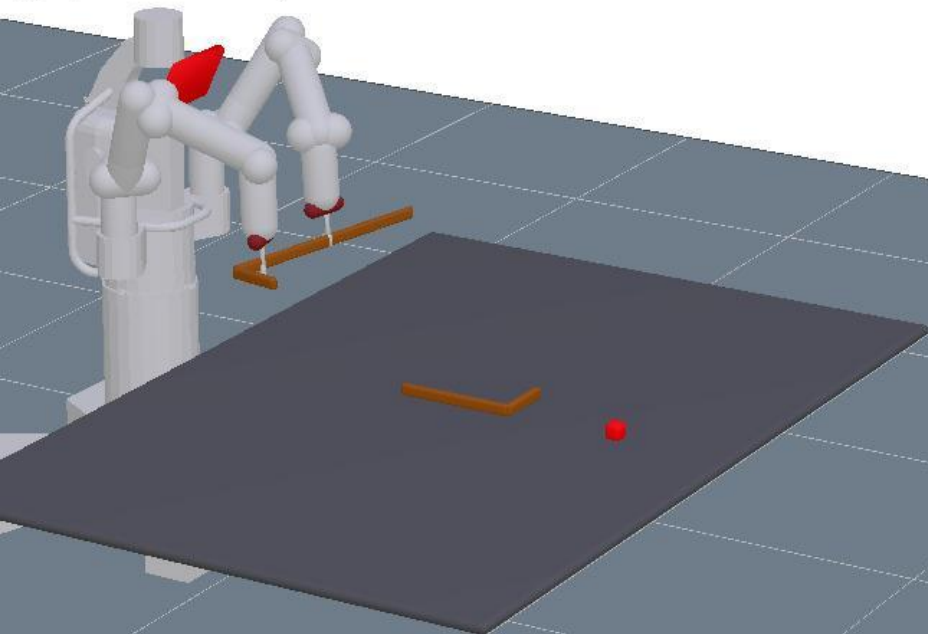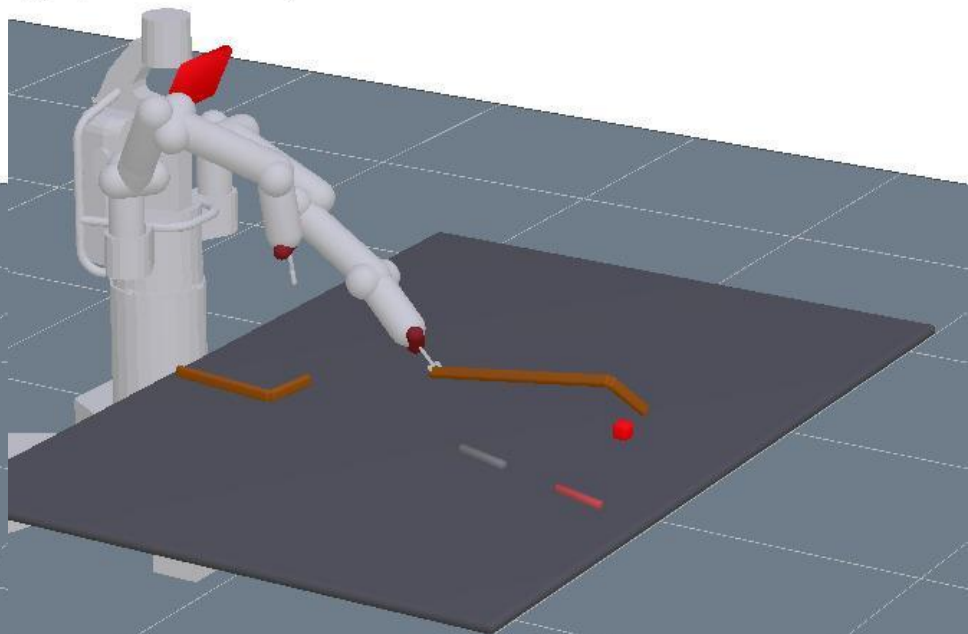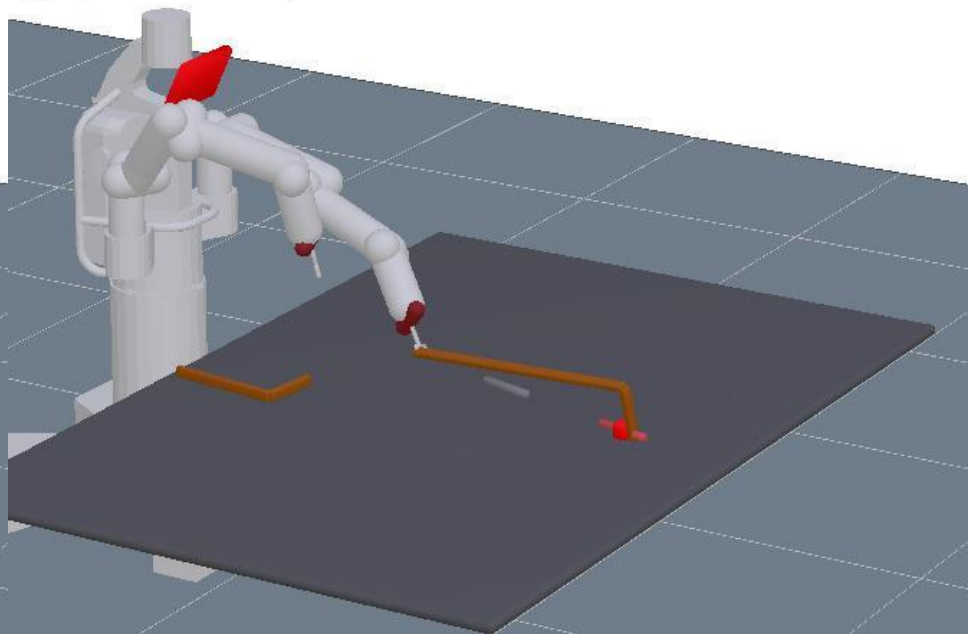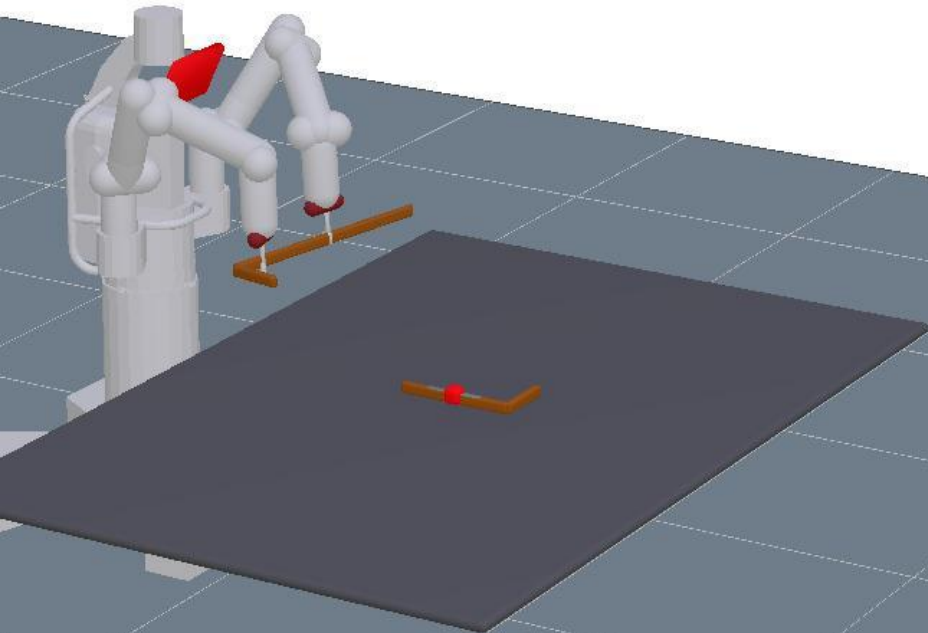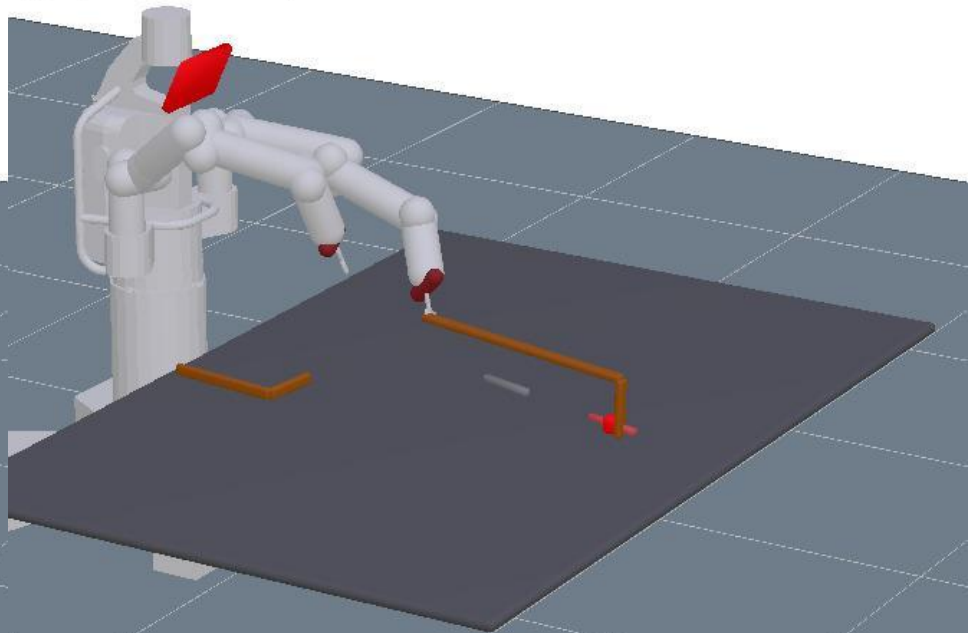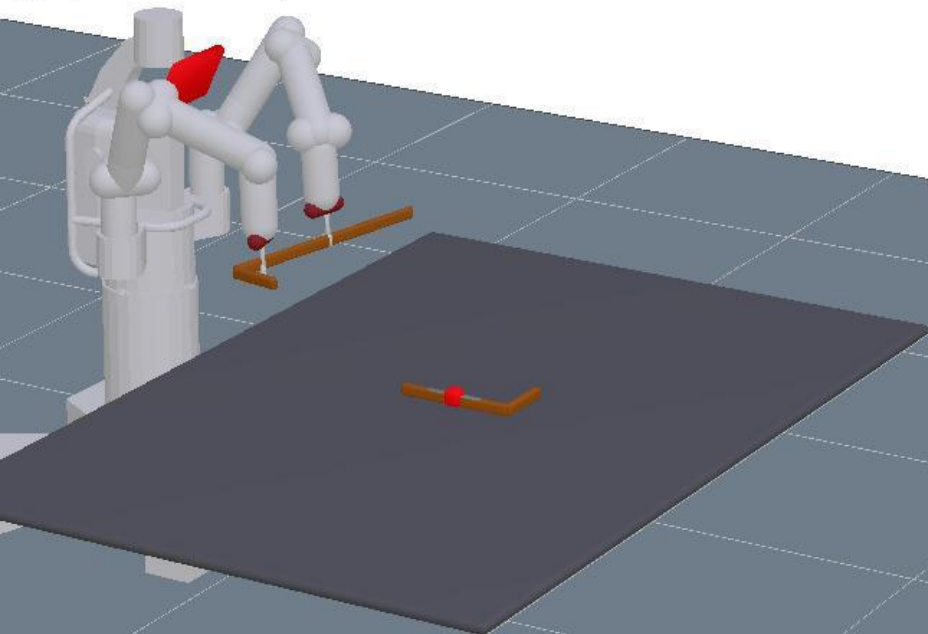Newton Steps:1000
mu:262144
nu:262144

	initial phase					grasp baxterR stick2					push stickTip2 stickTip table1					place baxterR stick2 table1					grasp baxterL stick1					push stick2 redBall table1					grasp baxterR redBall		
q(t_0)	q(t_1)	q(t_2)	q(t_3)	q(t_4)	q(t_5)	q(t_6)	q(t_7)	q(t_8)	q(t_9)	q(t_10)	q(t_11)	q(t_12)	q(t_13)	q(t_14)	q(t_15)	q(t_16)	q(t_17)	q(t_18)	q(t_19)	q(t_20)	q(t_21)	q(t_22)	q(t_23)	q(t_24)	q(t_25)	q(t_26)	q(t_27)	q(t_28)	q(t_29)	q(t_30)	q(t_31)	q(t_32)	q(t_33)
0,00	0,00	-0,00	-0,01	-0,01	-0,00	0,01	0,03	0,04	0,04	0,02	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75
0,08	0,08	0,00	-0,11	-0,21	-0,25	-0,19	0,03	0,30	0,55	0,69	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-0,08	-0,08	-0,08	-0,08	-0,09	-0,09	-0,09	-0,09	-0,09	-0,08	-0,07	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12
-1,00	-1,00	-0,78	-0,43	-0,00	0,40	0,68	0,71	0,61	0,47	0,35	-0,02	-0,09	-0,26	-0,53	-0,75	-0,61	-0,61	-0,61	-0,61	-0,61	-0,75	-0,75	-0,75	-0,75	-0,75	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
-1,00	-1,00	-1,00	-1,01	-1,02	-1,03	-1,04	-1,05	-1,06	-1,06	-1,05	0,68	0,51	0,19	-0,19	-0,53	-0,10	-0,10	-0,10	-0,10	-0,10	-0,28	-0,28	-0,28	-0,28	-0,28	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15
1,17	1,17	1,03	0,80	0,53	0,27	0,07	-0,00	-0,01	-0,01	-0,01	-0,06	-0,03	0,01	0,07	0,14	-0,00	-0,00	-0,00	-0,00	-0,00	-0,12	-0,12	-0,12	-0,12	-0,12	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-1,17	-1,17	-1,17	-1,18	-1,19	-1,20	-1,21	-1,22	-1,22	-1,21	-1,20	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	0,01	0,07	0,17	0,31	0,45	0,54	0,49	0,34	0,08	-0,21	-0,25	-0,20	-0,14
1,94	1,94	1,75	1,41	0,99	0,55	0,19	0,00	-0,07	-0,06	0,01	0,25	0,23	0,29	0,46	0,57	-0,28	-0,28	-0,28	-0,28	-0,28	-0,31	-0,19	-0,08	0,03	0,14	0,25	0,37	0,50	0,65	0,80	0,94	1,01	1,07
1,94	1,94	1,94	1,95	1,96	1,97	1,99	2,00	2,01	2,02	2,02	-1,03	-0,99	-0,92	-0,83	-0,71	-0,12	-0,12	-0,12	-0,12	-0,12	0,42	0,11	-0,29	-0,64	-0,86	-0,80	-0,48	-0,05	0,43	0,91	1,11	1,27	1,42
-0,67	-0,67	-0,81	-1,04	-1,28	-1,47	-1,55	-1,41	-1,15	-0,83	-0,54	0,01	0,12	0,24	0,18	-0,00	-0,94	-0,60	-0,30	-0,12	-0,03	-0,68	-0,80	-0,87	-0,89	-0,85	0,28	0,28	0,28	0,28	0,28	0,21	0,37	0,50
0,67	0,67	0,67	0,66	0,65	0,64	0,63	0,62	0,62	0,63	0,66	-1,16	-1,11	-1,03	-0,92	-0,77	-0,68	-0,71	-0,65	-0,55	-0,44	0,45	0,51	0,52	0,47	0,38	-0,76	-0,62	-0,44	-0,23	-0,00	-0,12	-0,14	-0,17
1,02	1,02	0,70	0,17	-0,41	-0,92	-1,19	-1,04	-0,66	-0,22	0,11	0,16	0,49	0,90	1,31	1,54	0,23	0,33	0,43	0,51	0,52	0,88	0,99	1,06	1,10	1,11	0,26	0,14	0,06	-0,01	-0,10	0,84	0,72	0,72
1,02	1,02	1,03	1,04	1,06	1,08	1,10	1,11	1,11	1,10	1,06	2,01	1,98	1,92	1,83	1,70	0,47	0,26	-0,00	-0,26	-0,49	0,18	0,04	-0,20	-0,48	-0,74	1,10	1,07	1,02	0,96	0,90	-0,81	-0,82	-0,85
0,50	0,50	0,56	0,67	0,81	0,97	1,11	1,20	1,26	1,26	1,21	-0,42	-0,61	-0,88	-1,17	-1,40	-0,56	-0,37	-0,16	0,07	0,28	2,07	2,05	2,01	1,94	1,84	-0,94	-1,02	-1,02	-0,96	-0,85	0,76	0,61	0,48
-0,50	-0,50	-0,50	-0,50	-0,50	-0,49	-0,49	-0,49	-0,48	-0,48	-0,47	0,70	0,76	0,85	0,97	1,13	0,02	0,16	0,36	0,55	0,73	0,20	0,12	0,11	0,12	0,12	1,71	1,56	1,37	1,17	0,95	1,64	1,89	2,12
						0,03	0,03	0,03	0,03	0,03	0,14	-0,31	-0,88	-1,30	-1,44	-0,60	-0,40	-0,19	0,01	0,15	-0,93	-0,83	-0,76	-0,71	-0,69	0,14	0,36	0,69	1,06	1,40	-0,80	-0,83	-0,85
						0,04	0,04	0,04	0,04	0,04	0,99	0,88	0,72	0,50	0,22	1,73	1,86	1,96	2,02	2,06	2,14	1,91	1,54	1,10	0,64	-0,68	-0,69	-0,71	-0,73	-0,77	0,10	0,11	0,11
						-0,17	-0,17	-0,18	-0,18	-0,18	1,05	0,74	0,43	0,13	-0,16	1,52	1,29	1,02	0,72	0,43	0,46	0,68	0,82	0,90	0,91	0,26	0,10	0,03	0,03	0,07	0,23	0,12	0,11
						0,52	0,52	0,52	0,52	0,52	-0,46	-0,46	-0,46	-0,46	-0,47	-1,47	-1,42	-1,32	-1,18	-1,05	-1,56	-1,21	-0,68	-0,15	0,23	0,88	0,80	0,69	0,54	0,38	1,26	1,12	0,98
						-0,56	-0,56	-0,56	-0,56	-0,56	0,02	0,02	0,02	0,02	0,02	1,32	1,53	1,76	1,97	2,12	0,23	0,32	0,39	0,44	0,48	0,53	0,81	1,05	1,25	1,38	0,52	0,52	0,51
						0,27	0,27	0,27	0,26	0,26	-1,27	-0,94	-0,55	-0,16	0,18	-0,73	-0,77	-0,80	-0,81	-0,80	0,50	0,51	0,52	0,52	0,52	-0,13	-0,07	-0,02	-0,02	-0,02	-0,13	-0,07	-0,02
						0,57	0,57	0,57	0,57	0,57	-0,19	-0,19	-0,19	-0,19	-0,19	-0,11	-0,50	-0,90	-1,27	-1,53	0,02	0,02	0,02	0,02	0,02	-0,76	-0,62	-0,46	-0,31	-0,18	0,02	0,02	0,02
											0,52	0,52	0,52	0,52	0,52	-0,26	-0,23	-0,13	-0,01	0,11	0,04	0,04	0,04	0,04	0,04	0,02	0,02	0,02	0,02	0,02	0,04	0,04	0,04
											-0,56	-0,56	-0,56	-0,56	-0,56	-0,49	-0,52	-0,56	-0,61	-0,67	-0,19	-0,19	-0,19	-0,19	-0,19	0,04	0,04	0,04	0,04	0,04	-0,19	-0,19	-0,19
											0,26	0,26	0,26	0,26	0,26	0,02	0,02	0,02	0,02	0,02	0,23	0,23	0,23	0,23	0,23	-0,19	-0,19	-0,19	-0,19	-0,19	-0,00	-0,00	-0,00
											0,57	0,57	0,57	0,57	0,57	0,04	0,04	0,04	0,04	0,04	0,16	0,16	0,16	0,16	0,16	0,23	0,23	0,23	0,23	0,23	0,00	0,00	0,00
																-0,19	-0,19	-0,19	-0,19	-0,19	-0,24	-0,24	-0,24	-0,24	-0,24	0,16	0,16	0,16	0,16	0,16	-0,02	-0,02	-0,02
																					0,80	0,80	0,80	0,80	0,80	-0,24	-0,24	-0,24	-0,24	-0,24	0,23	0,23	0,23
																					-0,43	-429,00	-0,43	-0,43	-0,43	0,80	0,80	0,80	0,80	0,80	0,16	0,16	0,16
																					0,18	0,18	0,18	0,18	0,18	-0,43	-0,43	-0,43	-0,43	-0,43	-0,24	-0,24	-0,24
																					0,38	0,38	0,38	0,38	0,38	0,18	0,18	0,18	0,18	0,18	0,67	0,67	0,67
																										0,38	0,38	0,38	0,38	0,38	-0,34	-0,34	-0,34
																															-0,06	-0,06	-0,06
																															0,66	0,66	0,66
																															0,80	0,80	0,80
																															-0,43	-0,43	-0,43
																															0,18	0,18	0,18
																															0,38	0,38	0,38

time:10/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
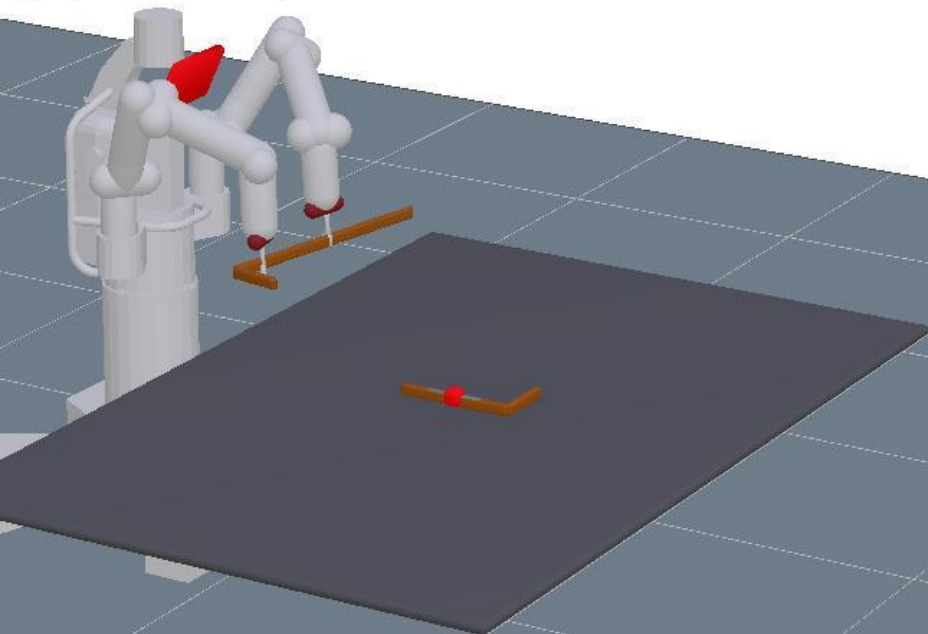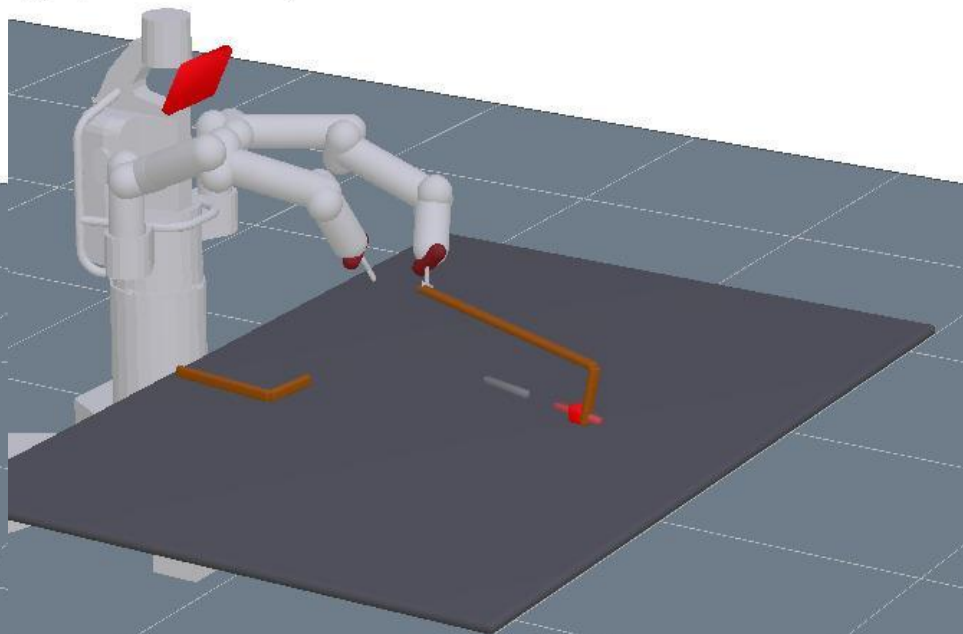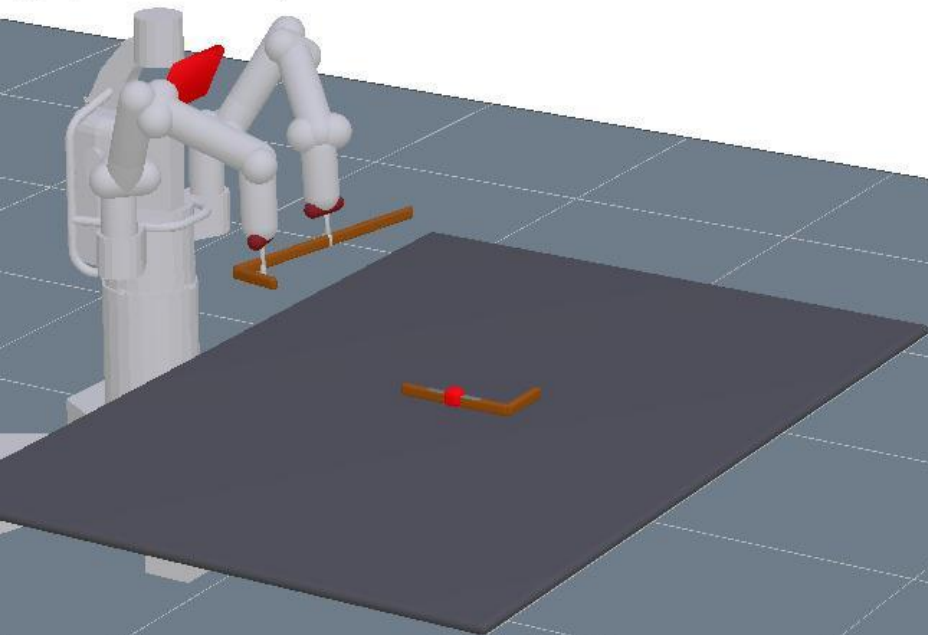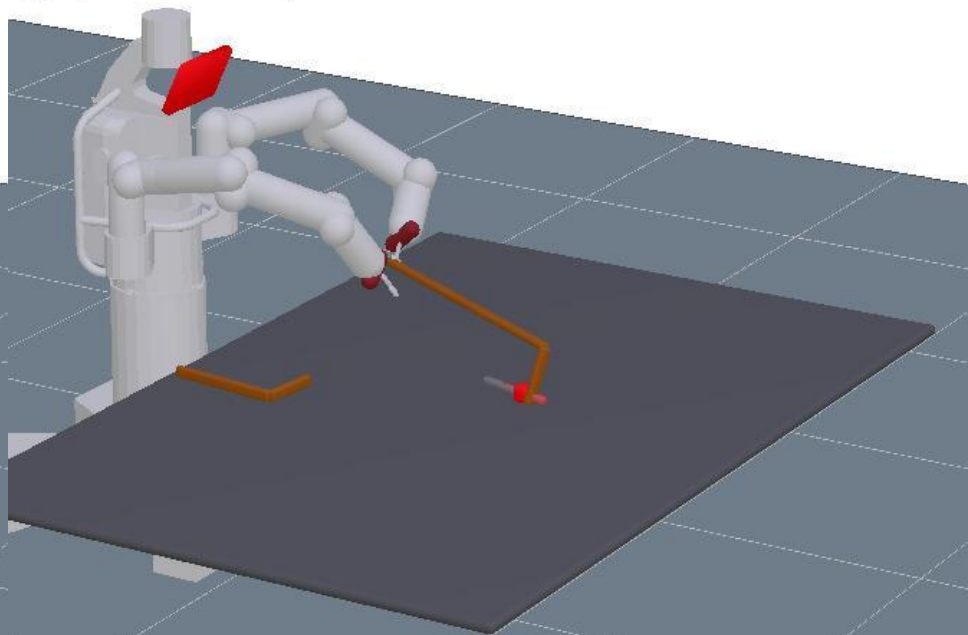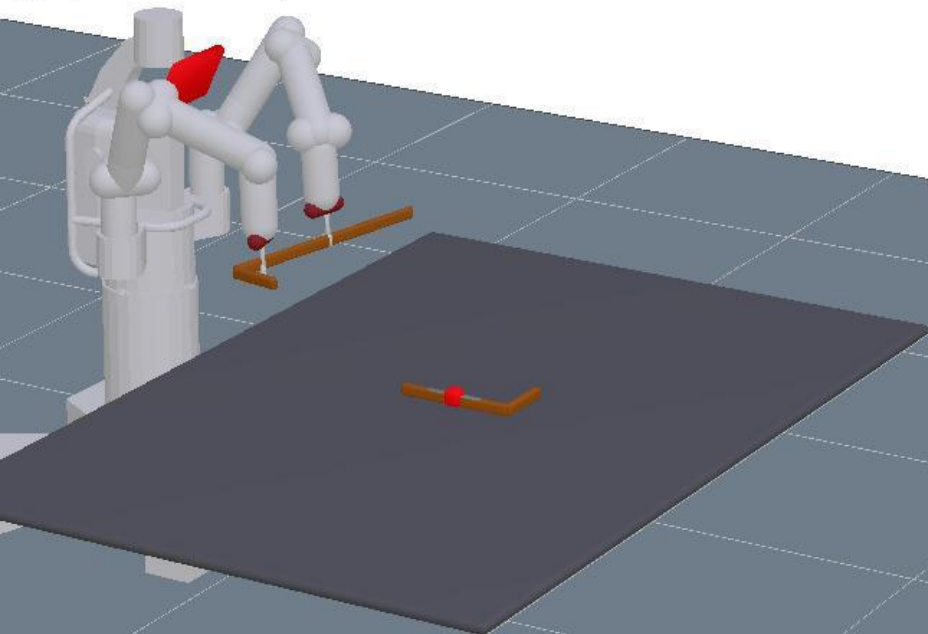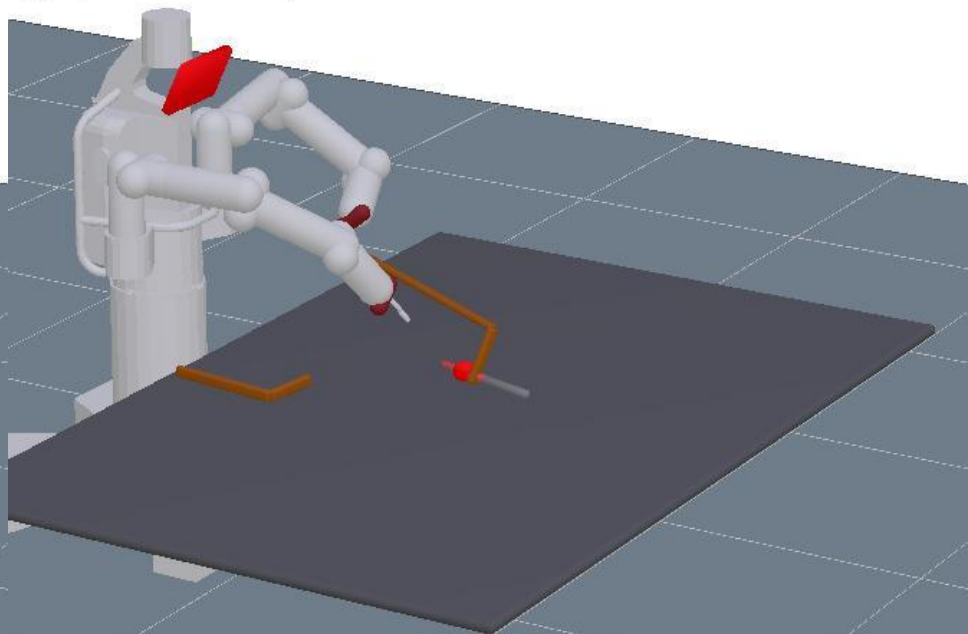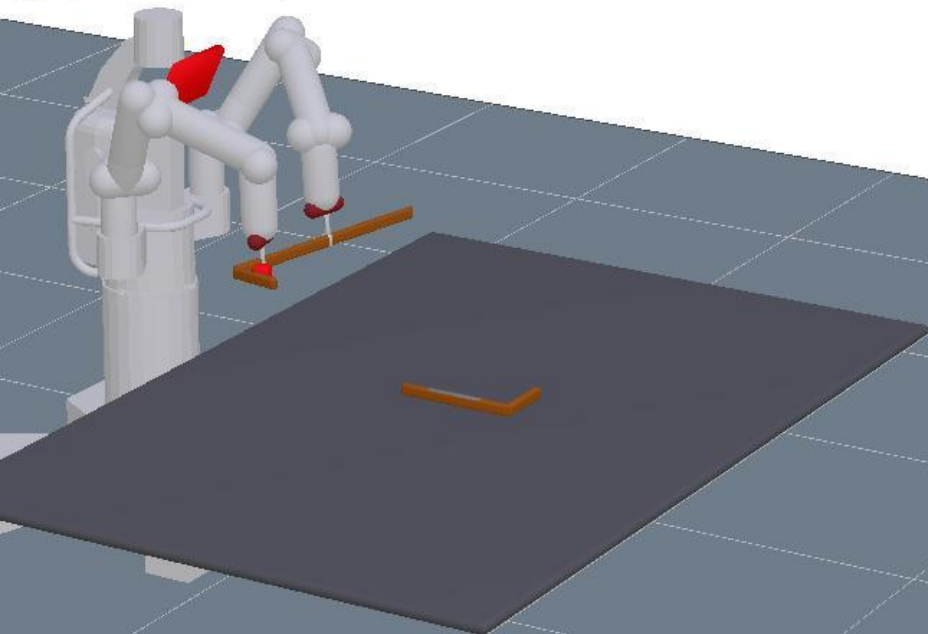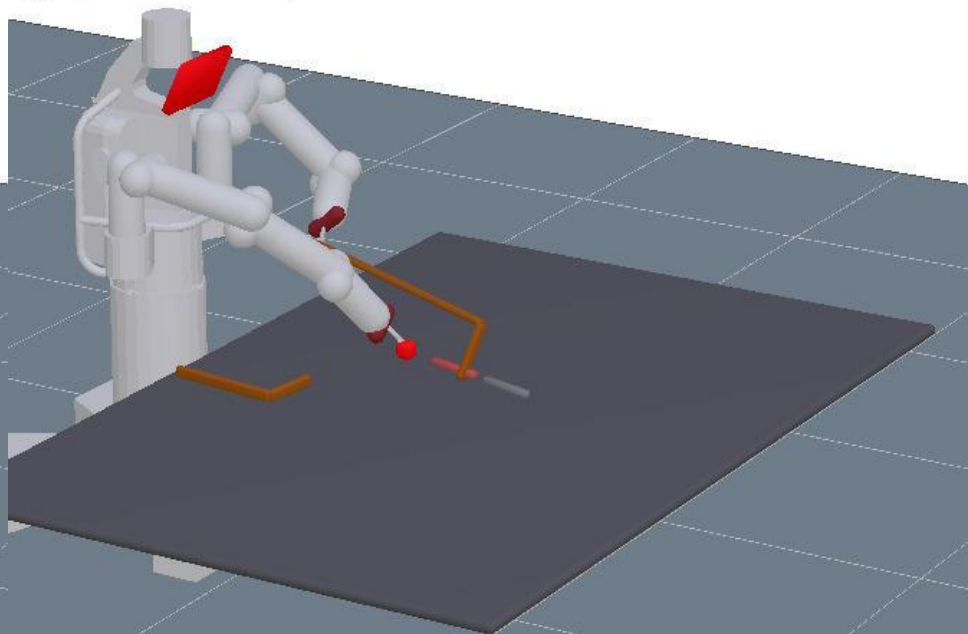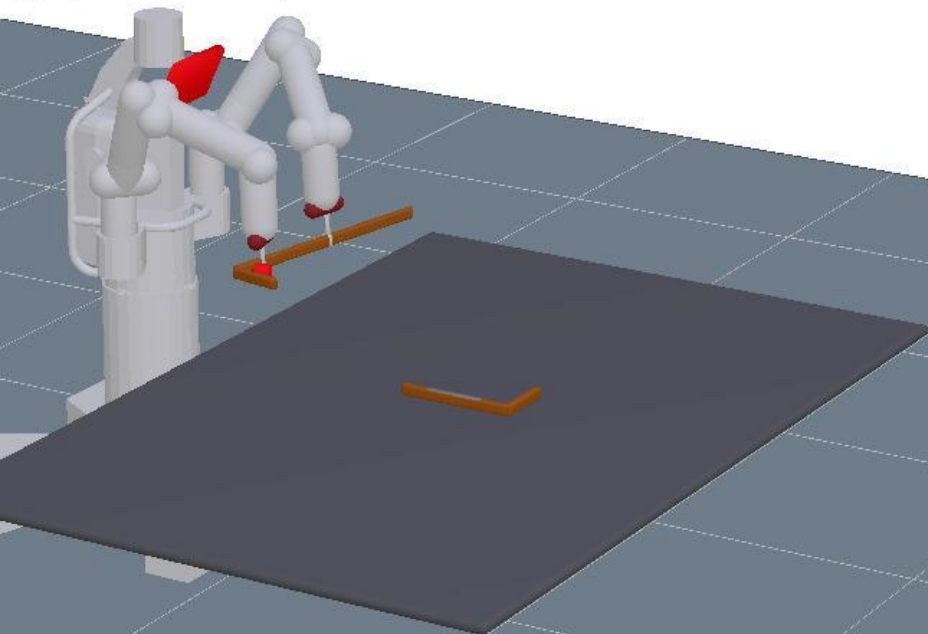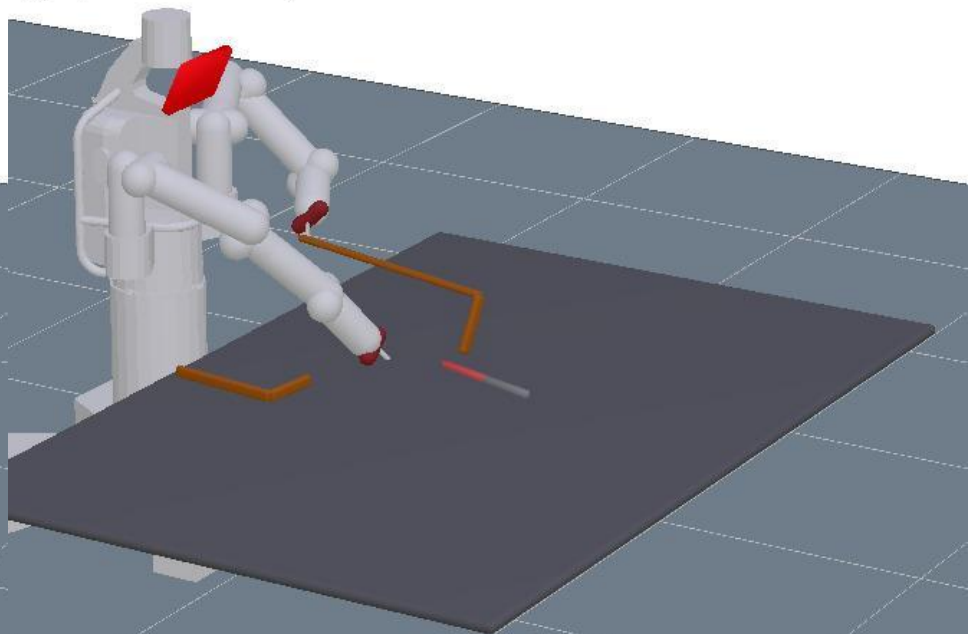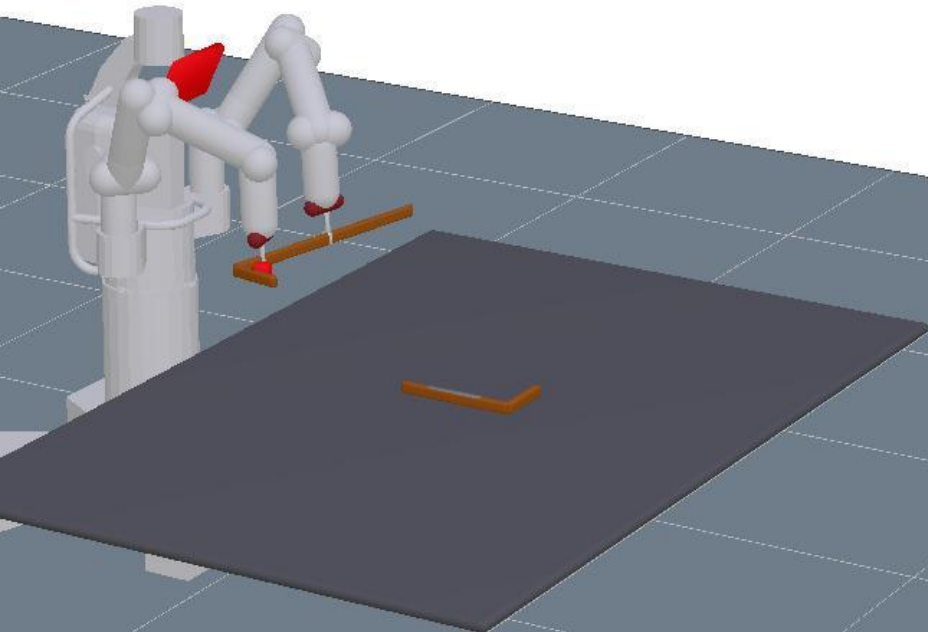Newton Steps:1000
mu:262144
nu:262144

initial phase						grasp baxterR stick2					push stickTip2 stickTip table1					place baxterR stick2 table1					grasp baxterL stick1					push stick2 redBall table1					grasp baxterR redBall		
q(t_0)	q(t_1)	q(t_2)	q(t_3)	q(t_4)	q(t_5)	q(t_6)	q(t_7)	q(t_8)	q(t_9)	q(t_10)	q(t_11)	q(t_12)	q(t_13)	q(t_14)	q(t_15)	q(t_16)	q(t_17)	q(t_18)	q(t_19)	q(t_20)	q(t_21)	q(t_22)	q(t_23)	q(t_24)	q(t_25)	q(t_26)	q(t_27)	q(t_28)	q(t_29)	q(t_30)	q(t_31)	q(t_32)	q(t_33)
0,00	0,00	-0,00	-0,01	-0,01	-0,00	0,01	0,03	0,04	0,04	0,02	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75	-0,75
0,08	0,08	0,00	-0,11	-0,21	-0,25	-0,19	0,03	0,30	0,55	0,69	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-0,08	-0,08	-0,08	-0,08	-0,09	-0,09	-0,09	-0,09	-0,09	-0,08	-0,07	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,32	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12	-0,12
-1,00	-1,00	-0,78	-0,43	-0,00	0,40	0,68	0,71	0,61	0,47	0,35	-0,02	-0,09	-0,26	-0,53	-0,75	-0,61	-0,61	-0,61	-0,61	-0,61	-0,75	-0,75	-0,75	-0,75	-0,75	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
-1,00	-1,00	-1,00	-1,01	-1,02	-1,03	-1,04	-1,05	-1,06	-1,06	-1,05	0,68	0,51	0,19	-0,19	-0,53	-0,10	-0,10	-0,10	-0,10	-0,10	-0,28	-0,28	-0,28	-0,28	-0,28	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15
1,17	1,17	1,03	0,80	0,53	0,27	0,07	-0,00	-0,01	-0,01	-0,01	-0,06	-0,03	0,01	0,07	0,14	-0,00	-0,00	-0,00	-0,00	-0,00	-0,12	-0,12	-0,12	-0,12	-0,12	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28	-0,28
-1,17	-1,17	-1,17	-1,18	-1,19	-1,20	-1,21	-1,22	-1,22	-1,21	-1,20	0,32	0,32	0,32	0,32	0,32	-0,75	-0,75	-0,75	-0,75	-0,75	0,01	0,07	0,17	0,31	0,45	0,54	0,49	0,34	0,08	-0,21	-0,25	-0,20	-0,14
1,94	1,94	1,75	1,41	0,99	0,55	0,19	0,00	-0,07	-0,06	0,01	0,25	0,23	0,29	0,46	0,57	-0,28	-0,28	-0,28	-0,28	-0,28	-0,31	-0,19	-0,08	0,03	0,14	0,25	0,37	0,50	0,65	0,80	0,94	1,01	1,07
1,94	1,94	1,94	1,95	1,96	1,97	1,99	2,00	2,01	2,02	2,02	-1,03	-0,99	-0,92	-0,83	-0,71	-0,12	-0,12	-0,12	-0,12	-0,12	0,42	0,11	-0,29	-0,64	-0,86	-0,80	-0,48	-0,05	0,43	0,91	1,11	1,27	1,42
-0,67	-0,67	-0,81	-1,04	-1,28	-1,47	-1,55	-1,41	-1,15	-0,83	-0,54	0,01	0,12	0,24	0,18	-0,00	-0,94	-0,60	-0,30	-0,12	-0,03	-0,68	-0,80	-0,87	-0,89	-0,85	0,28	0,28	0,28	0,28	0,28	0,21	0,37	0,50
0,67	0,67	0,67	0,66	0,65	0,64	0,63	0,62	0,62	0,63	0,66	-1,16	-1,11	-1,03	-0,92	-0,77	-0,68	-0,71	-0,65	-0,55	-0,44	0,45	0,51	0,52	0,47	0,38	-0,76	-0,62	-0,44	-0,23	-0,00	-0,12	-0,14	-0,17
1,02	1,02	0,70	0,17	-0,41	-0,92	-1,19	-1,04	-0,66	-0,22	0,11	0,16	0,49	0,90	1,31	1,54	0,23	0,33	0,43	0,51	0,52	0,88	0,99	1,06	1,10	1,11	0,26	0,14	0,06	-0,01	-0,10	0,84	0,78	0,72
1,02	1,02	1,03	1,04	1,06	1,08	1,10	1,11	1,11	1,10	1,06	2,01	1,98	1,92	1,83	1,70	0,47	0,26	-0,00	-0,26	-0,49	0,18	0,04	-0,20	-0,48	-0,74	1,10	1,07	1,02	0,96	0,90	-0,81	-0,82	-0,85
0,50	0,50	0,56	0,67	0,81	0,97	1,11	1,20	1,26	1,26	1,21	-0,42	-0,61	-0,88	-1,17	-1,40	-0,56	-0,37	-0,16	0,07	0,28	2,07	2,05	2,01	1,94	1,84	-0,94	-1,02	-1,02	-0,96	-0,85	0,76	0,61	0,48
-0,50	-0,50	-0,50	-0,50	-0,50	-0,49	-0,49	-0,49	-0,48	-0,48	-0,47	0,70	0,76	0,85	0,97	1,13	0,02	0,16	0,36	0,55	0,73	0,20	0,12	0,11	0,12	0,12	1,71	1,56	1,37	1,17	0,95	1,64	1,89	2,12
						0,03	0,03	0,03	0,03	0,03	0,14	-0,31	-0,88	-1,30	-1,44	-0,60	-0,40	-0,19	0,01	0,15	-0,93	-0,83	-0,76	-0,71	-0,69	0,14	0,36	0,69	1,06	1,40	-0,80	-0,83	-0,85
						0,04	0,04	0,04	0,04	0,04	0,99	0,88	0,72	0,50	0,22	1,73	1,86	1,96	2,02	2,06	2,14	1,91	1,54	1,10	0,64	-0,68	-0,69	-0,71	-0,73	-0,77	0,10	0,11	0,11
						-0,17	-0,17	-0,18	-0,18	-0,18	1,05	0,74	0,43	0,13	-0,16	1,52	1,29	1,02	0,72	0,43	0,46	0,68	0,82	0,90	0,91	0,26	0,10	0,03	0,03	0,07	0,23	0,12	0,03
						0,52	0,52	0,52	0,52	0,52	-0,46	-0,46	-0,46	-0,46	-0,47	-1,47	-1,42	-1,32	-1,18	-1,05	-1,56	-1,21	-0,68	-0,15	0,23	0,88	0,80	0,69	0,54	0,38	1,26	1,12	0,98
						-0,56	-0,56	-0,56	-0,56	-0,56	0,02	0,02	0,02	0,02	0,02	1,32	1,53	1,76	1,97	2,12	0,23	0,32	0,39	0,44	0,48	0,53	0,81	1,05	1,25	1,38	0,52	0,52	0,51
						0,27	0,27	0,27	0,26	0,26	0,04	0,04	0,04	0,04	0,04	-1,27	-0,94	-0,55	-0,16	0,18	-0,73	-0,77	-0,80	-0,81	-0,80	0,50	0,51	0,52	0,52	0,52	-0,13	-0,07	-0,02
						0,57	0,57	0,57	0,57	0,57	-0,19	-0,19	-0,19	-0,19	-0,19	-0,11	-0,50	-0,90	-1,27	-1,53	0,02	0,02	0,02	0,02	0,02	-0,76	-0,62	-0,46	-0,31	-0,18	0,02	0,02	0,02
											0,52	0,52	0,52	0,52	0,52	-0,26	-0,23	-0,13	-0,01	0,11	0,04	0,04	0,04	0,04	0,04	0,02	0,02	0,02	0,02	0,02	0,04	0,04	0,04
											-0,56	-0,56	-0,56	-0,56	-0,56	-0,49	-0,52	-0,56	-0,61	-0,67	-0,19	-0,19	-0,19	-0,19	-0,19	0,04	0,04	0,04	0,04	0,04	-0,19	-0,19	-0,19
											0,26	0,26	0,26	0,26	0,26	0,02	0,02	0,02	0,02	0,02	0,23	0,23	0,23	0,23	0,23	-0,19	-0,19	-0,19	-0,19	-0,19	-0,00	-0,00	-0,00
											0,57	0,57	0,57	0,57	0,57	0,04	0,04	0,04	0,04	0,04	0,16	0,16	0,16	0,16	0,16	0,23	0,23	0,23	0,23	0,23	0,00	0,00	0,00
																-0,19	-0,19	-0,19	-0,19	-0,19	-0,24	-0,24	-0,24	-0,24	-0,24	0,16	0,16	0,16	0,16	0,16	-0,02	-0,02	-0,02
																					0,80	0,80	0,80	0,80	0,80	-0,24	-0,24	-0,24	-0,24	-0,24	0,23	0,23	0,23
																					-0,43	-429,00	-0,43	-0,43	-0,43	0,80	0,80	0,80	0,80	0,80	0,16	0,16	0,16
																					0,18	0,18	0,18	0,18	0,18	-0,43	-0,43	-0,43	-0,43	-0,43	-0,24	-0,24	-0,24
																					0,38	0,38	0,38	0,38	0,38	0,18	0,18	0,18	0,18	0,18	0,67	0,67	0,67
																										0,38	0,38	0,38	0,38	0,38	-0,34	-0,34	-0,34
																															-0,06	-0,06	-0,06
																															0,66	0,66	0,66
																															0,80	0,80	0,80
																															-0,43	-0,43	-0,43
																															0,18	0,18	0,18
																															0,38	0,38	0,38

time:11/34 | cost for each level: 0.6 0 0 8.83215 | constraint violation:0.611116

(grasp baxterR stick2)
(push stickTip2 stickTip table1)
(place baxterR stick2 table1)
(grasp baxterL stick)
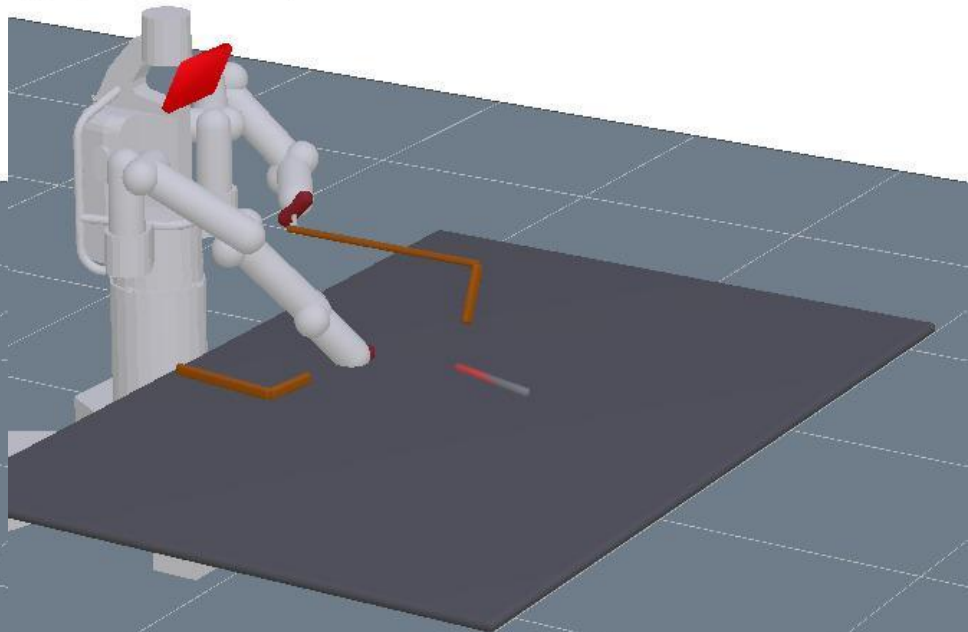(push stickTip redBall table1)
(grasp baxterR redBall)

StepsPerPhase:5
Newton Steps:1000
mu:262144
nu:262144

Three level of optimization:

- first level involves only optimizing over configurations at time steps right at the switch (fast)

- second level involves optimization over a sequence of switches of terminating action sequences

- third level denotes the optimization problem over the full path

source: https://docs.google.com/presentation/d/1djPrK1RTnFvBtI88jT_3KqCHke0bARaW/edit#slide=id.p65

Huge Search Tree!

problem	1	2	3	4	5	6
tree size	12916	34564	7312	12242	12242	3386
branching	10.66	13.63	9.25	10.52	10.52	7.63
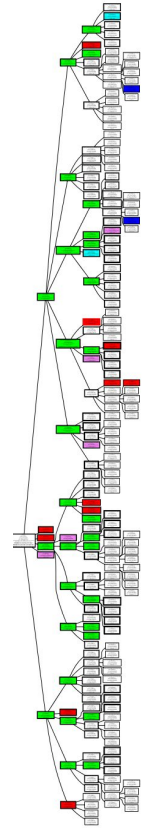
Experimental Setup

1-3 slides

Description of the experimental evaluation setting

❖ What is the domain(s), e.g., datasets, tasks, robot hardware setups?

❖ What are the baseline(s)?

❖ What scientific hypotheses are tested?

How did the authors evaluate the success of their approach?

❖ Clear description of the metrics that will be used

Discussion of Results

1-2 slides

What conclusions are drawn from the results by the authors?

❖ What insights are gained from the experiments?

❖ What strengths and weaknesses of the proposed method are illustrated by the results?

Are the stated conclusions fully backed by the results and references?

❖ If so, why? (Recap the relevant supporting evidences from the given results + refs)

❖ If not, what are the additional experiments / comparisons that can further support/repudiate the conclusions of the paper?

Results (Video)

Video Here
https://www.youtube.com/watch
?v=-L4tCIGXKBE

Results
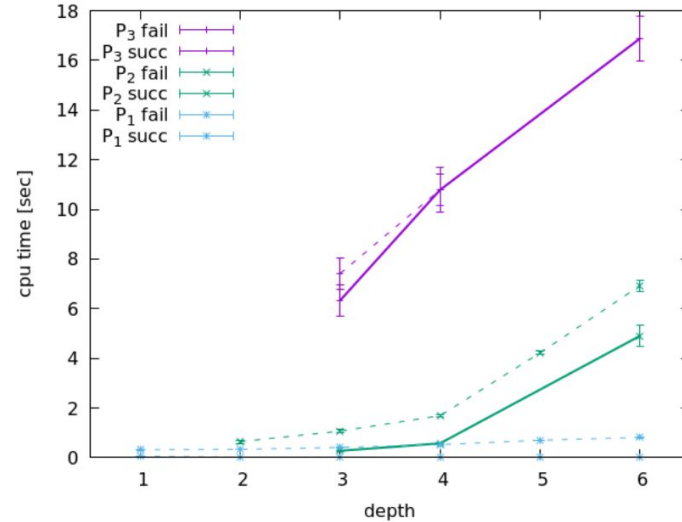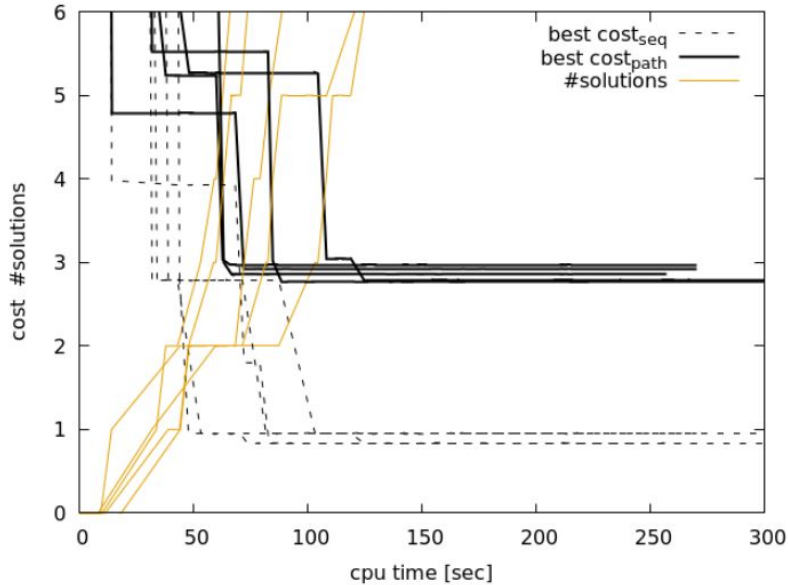
non-real-time

Fig. 5. Mean run times for the computation of the different bounds (solving $\mathcal{P}_1, \mathcal{P}_2, \mathcal{P}_3$), depending on feasibility and infeasibility.

Critique / Limitations / Open Issues

1-2 slides

Not real time, could be computationally expensive depending on how much to search and how well optimization steps.

For each tree

What are the key limitations of the proposed approach / ideas? (e.g. does it require strong assumptions that are unlikely to be practical? Computationally expensive? Require a lot of data?)

Are there any practical challenges in deploying the approach on physical robots in the real world? Are there any safety or ethical concerns of using such approach?

If follow-up work has addressed some of these limitations, include pointers to that. But don't limit your discussion only to the problems / limitations that have already been addressed.

Critique / Limitations / Open Issues

Efficiency:

The branching factor can be large, making search expensive.

"A significant portion of computation time is spent on trying to solve infeasible problems."

Depends on hand coded action operators and the path constraints they imply

The proposed method is primarily a planner and not designed for executing the plans.

Primitives are executive by human in reactive manner while planned solutions is not reactive

Deterministic Physics (ball example)

Future Work for Paper / Reading

Efficient tree pruning or search strategies could be beneficial.

Early indicators or classifiers to predict infeasibility could make the solver more efficient.

Learning primitives from human (or reduce the set of primitives)

Other higher level planner options (LLM)

Takeaways

Hierarchical Planning

Comparative Study with Humans

Understanding of Challenge of Physics-Based Planning

Exploit Interactions to Reduce Search Space
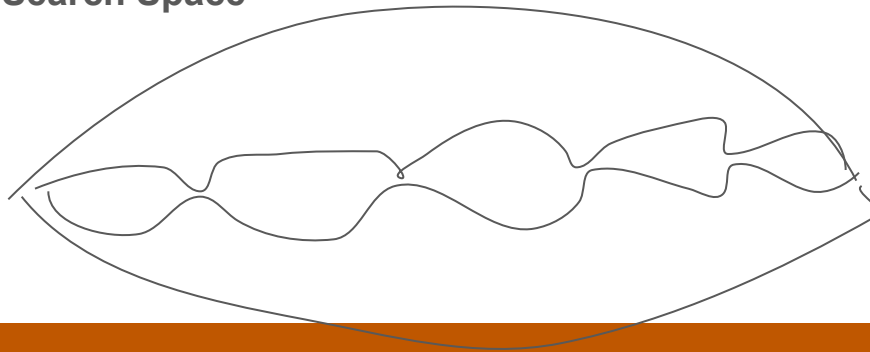
Extended Readings

Table 1 Multimodal motion planning (MMMP) and task and motion planning (TAMP) approaches (listed roughly chronologically within each cell), based on how they solve hybrid constraint satisfaction problems and how they integrate constraint satisfaction with action sequencing

	Pre-discretized	Sampling	Optimization
Satisfaction first	Ferrer-Mestres et al. (84, 85)[b]	Siméon et al. (22)[a] Hauser et al. (13, 14, 29)[a] Garrett et al. (21, 86)[b] Krontiris & Bekris (87, 88)[a] Akbari & Rosell (89)[b] Vega-Brown & Roy (90)[a]	
Interleaved	Dornhege et al. (62, 63, 91)[b] Gaschler et al. (92–94)[b] Colledanchise et al. (95)[b]	Gravot et al. (96, 97)[b] Stilman et al. (23, 98, 99)[a] Plaku & Hager (100)[a] Kaelbling & Lozano-Pérez (101, 102)[b] Barry et al. (30, 103, 104)[a] Garrett et al. (70, 71)[b] Thomason & Knepper (105)[b] Kim et al. (106, 107)[b] Kingston et al. (108)[a]	Fernández-González et al. (109)[b]
Sequencing first	Nilsson (3)[b] Erdem et al. (74, 75)[b] Lagriffoul et al. (65–67)[b] Pandey et al. (110, 111)[b] Lozano-Pérez & Kaelbling (112)[b] Dantam et al. (77–79)[b] Lo et al. (113)[b]	Wolfe et al. (114)[b] Srivastava et al. (60, 76)[b] Garrett et al. (55, 73)[b]	Toussaint et al. (61, 68, 69)[b] Shoukry et al. (81–83)[b] Hadfield-Menell et al. (115)[b]

[a] Approaches for MMMP.
[b] Approaches for TAMP.

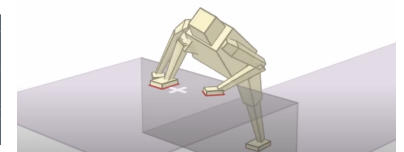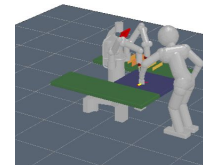**Today's paper**

Integrated Task and Motion Planning
https://www.annualreviews.org/doi/pdf/10.1146/annurev-control-091420-084139

Multi-Bound Tree Search for Logic-Geometric Programming in Cooperative Manipulation Domains
https://ieeexplore-ieee-org.ezproxy.lib.utexas.edu/document/7989464

Discovery of Complex Behaviors through Contact-Invariant Optimization
https://dl-acm-org.ezproxy.lib.utexas.edu/doi/10.1145/2185520.2185539

Summary

1 slide

Approximately one bullet for each of the following

❖   Problem the reading is discussing

❖   Why is it important and hard

❖   What is the key limitation of prior work

❖   What is the key insight(s) (try to do in 1-3) of the proposed work

❖   What did they demonstrate by this insight? (tighter theoretical bounds, state of the art performance on X, etc)

Summary

1. **Differentiable physics in TAMP**

2. **Hard due to nature of physical interactions.**

3. **Hierarchical planning, use of modes (action phases)**

4. **Human-like performance (planned) on motion planning that involves using tools**