Two- and Three-dimensional Caging-Based Grasping of Objects of Various Shapes with Circular Robots and Multi-Fingered Hands


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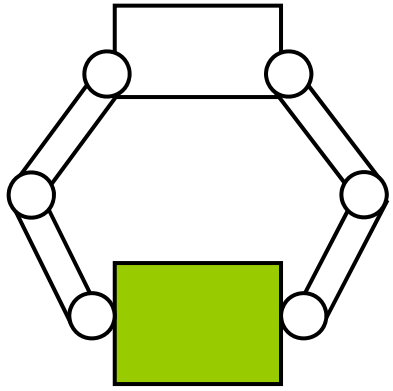
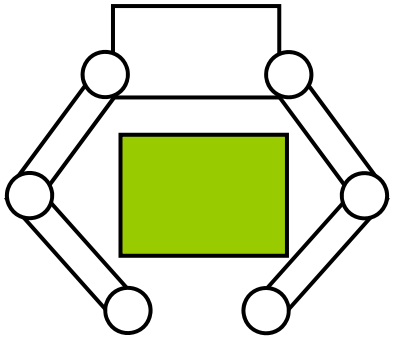
Background: Grasping vs. Caging

- Conventional Grasping



  - Object is localized
  - Need for force control

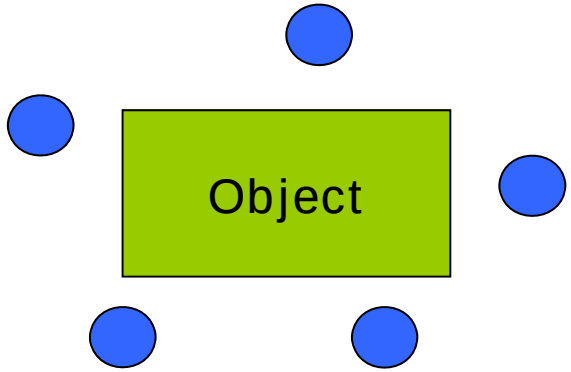
- Conventional Caging [Rimon 99]

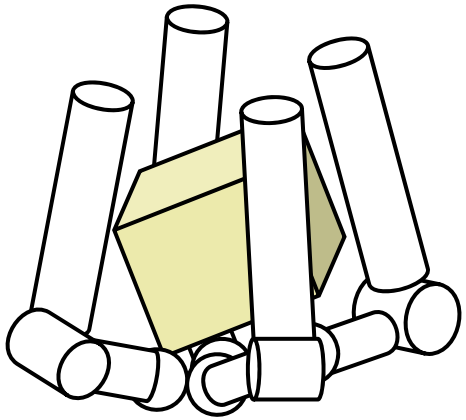


  - Object is movable
  - No need for force control

Caging

- Easily executed by today's robots
- But… object movement is not allowed in some applications
  - Possible inaccurate object placement
  - Possible collisions



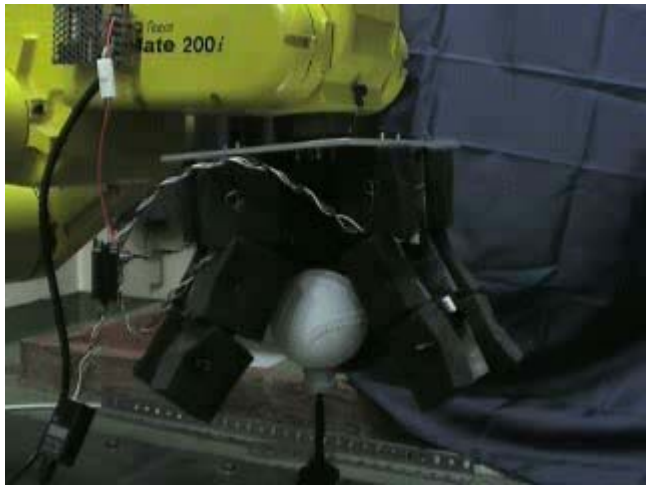


Motivation

- To establish a new approach to grasping with the merit of caging:

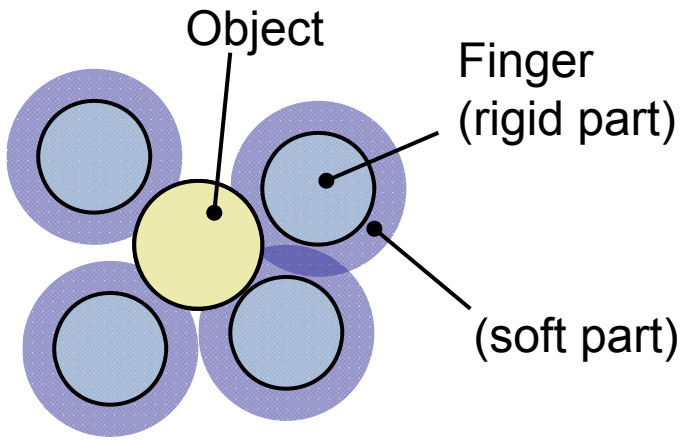
"Caging-based grasping"

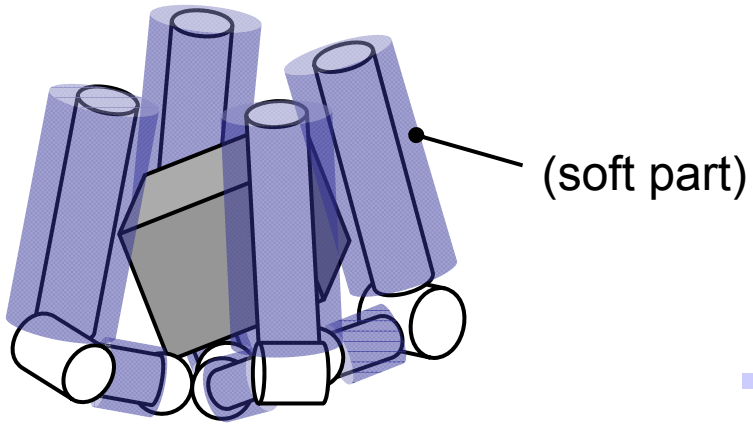
[Maeda 2012 ICRA]



What is caging-based grasping?

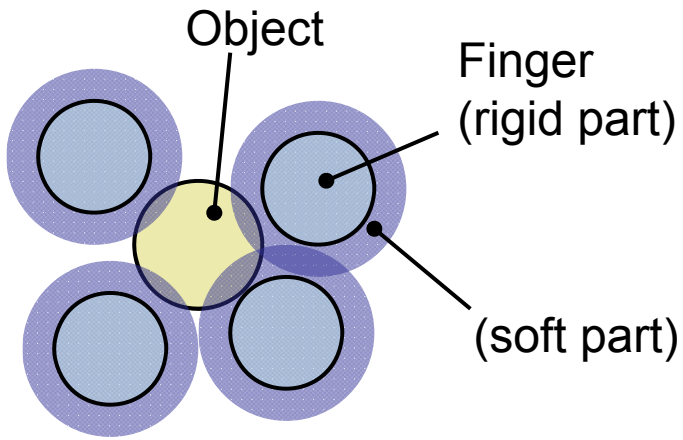
- A robot hand with rigid and soft parts is used
  - Rigid parts cage the object
  - Soft parts achieve a complete grasp by their deformation

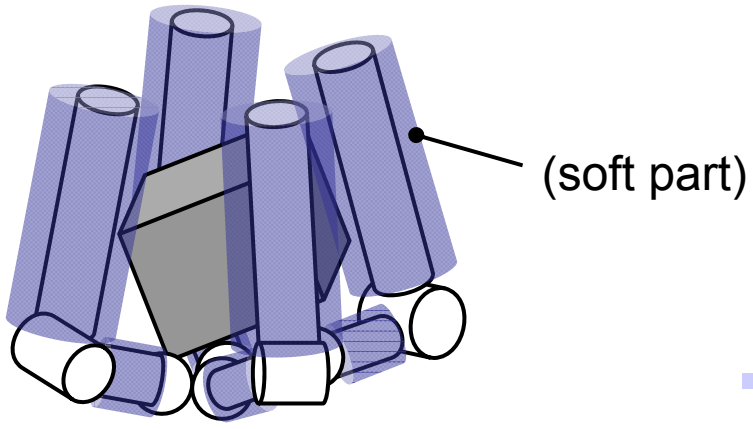




Merit of caging-based grasping

- Grasping by position-controlled hands
  - No need for force sensing/control
  - Only **geometrical analysis** is necessary to achieve grasping

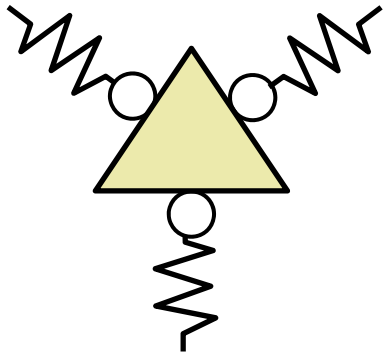




Previous studies on grasping by position-controlled hands

- Compliant grasps

(e.g., [Cutkosky and Kao 89] [Inoue and Hirai 08])



  - No need for force sensing or explicit force control
  - **Mechanical analysis** on grasp stability is necessary to guarantee successful grasping

Objective

- Only two cases are considered in our previous study [Maeda 2012 ICRA]

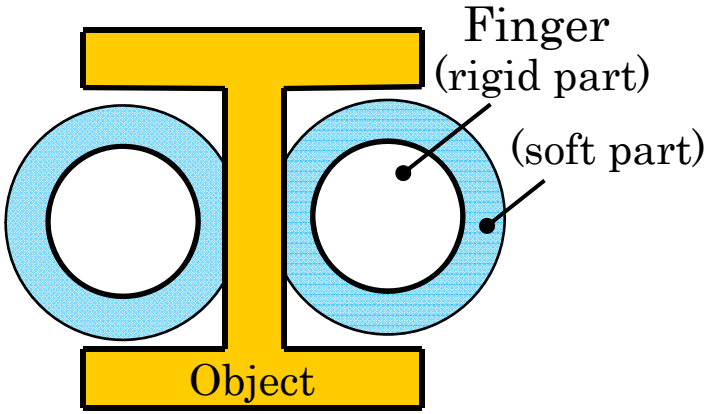
2D Grasping of circular objects by three circular robots

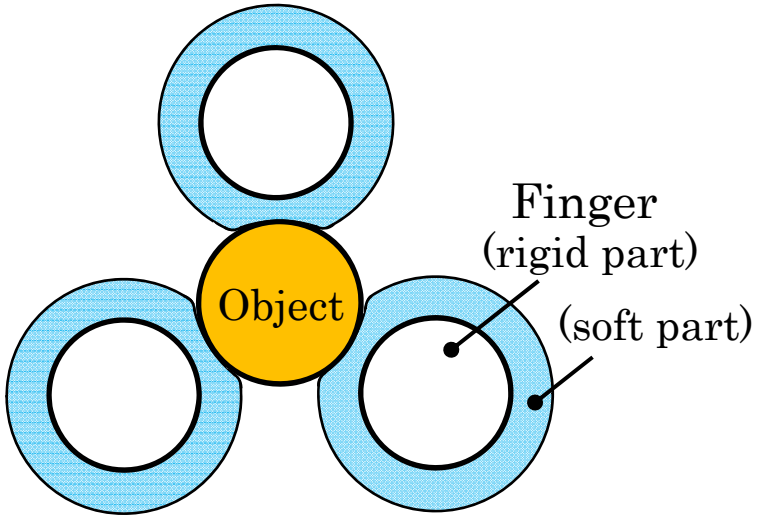
3D Grasping of spherical objects by a three-fingered hand

Caging-based grasping of various objects by various hands

Robot hands considered (for 2D grasps)

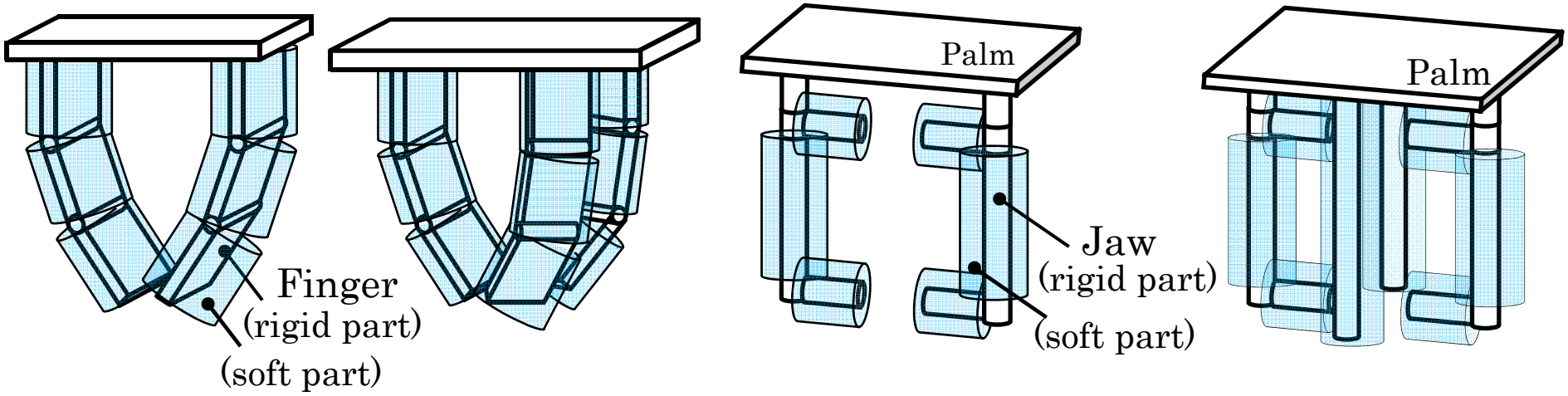
- Two or three circular robots (circular “fingers”)





Robot hands considered (for 3D grasps)

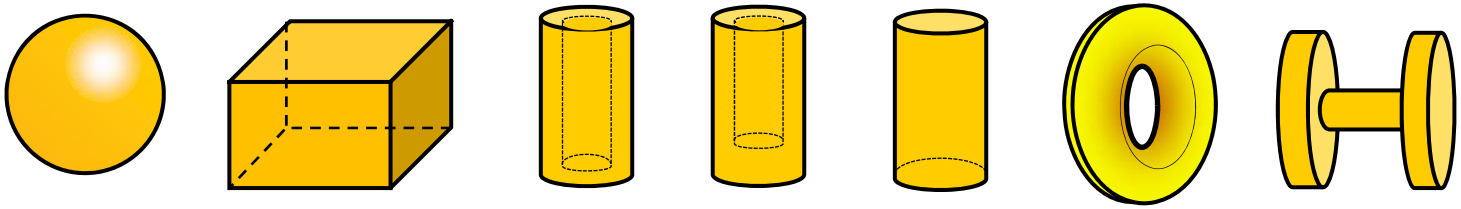
- For 3D grasps
  - Two- or three-fingered articulated hands
  - Two- or four-jaw parallel grippers (1 DOF)



Objects considered

- For 2D grasps

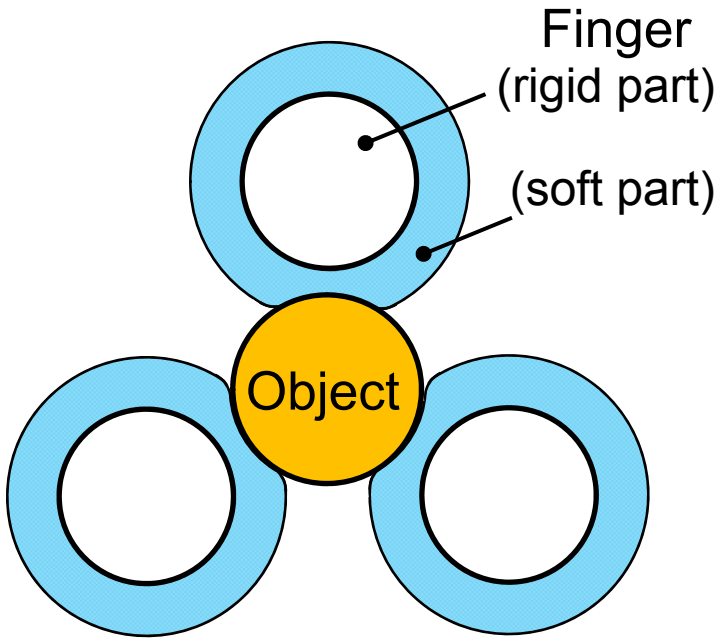
- For 3D grasps



  - Graspable
  - Appropriate as shape primitives

Definition of caging-based grasping

- Rigid-part caging condition
  - To make the object caged
    - Closed-region formation
    - Object inside
    - No interference

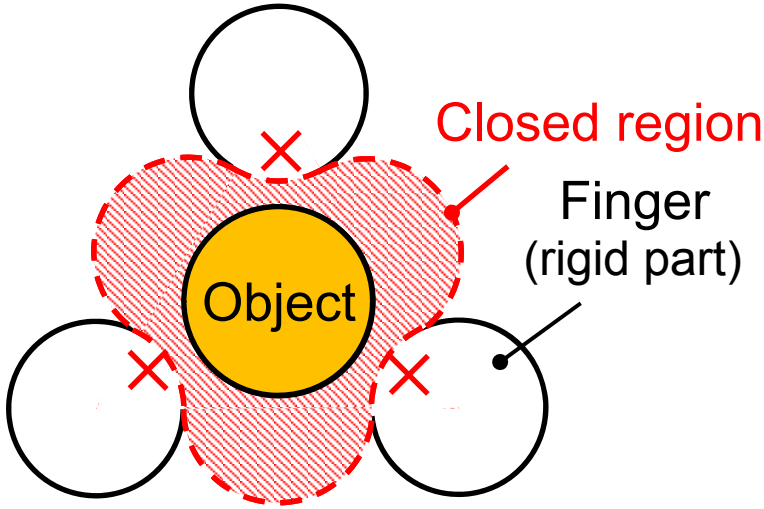


- Soft-part deformation condition
  - To complete grasping

Rigid-part caging condition

- **Closed-region formation**

  The closed region through which the object cannot pass is formed by the rigid parts of the hand.



- **Object inside**

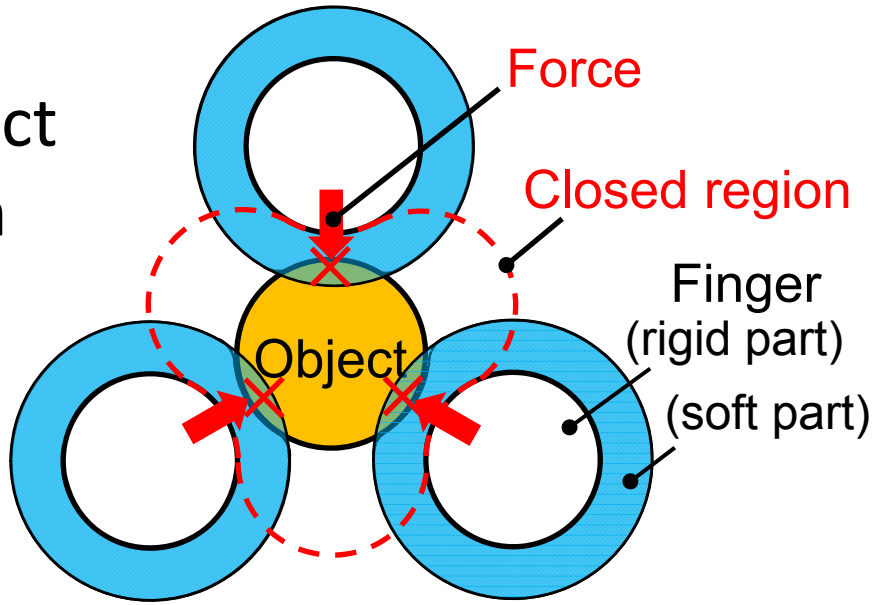
  The object is in the closed region formed by the rigid parts of the hand.

- **No interference**

  The rigid parts of the hand do not overlap with the object.

Soft-part deformation condition

Assuming that the soft parts of the hand become rigid, the object cannot exist in the closed region for caging.



Soft parts deform

↓

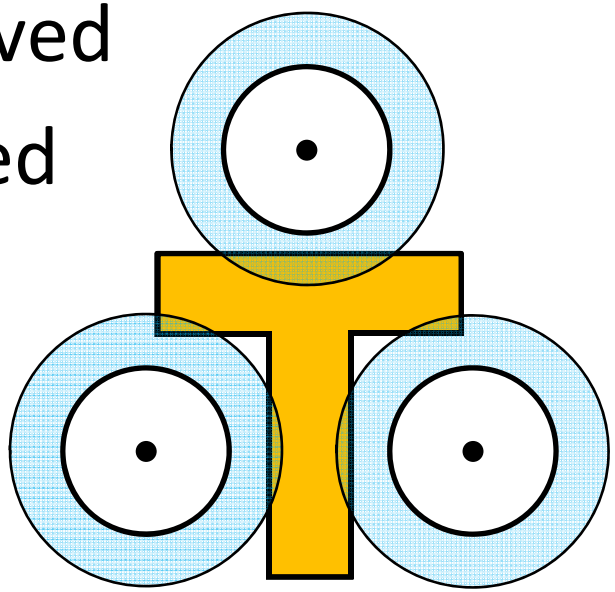
Reaction forces are applied to the object

↓

Grasping is achieved

Derivation of concrete conditions of caging-based grasping

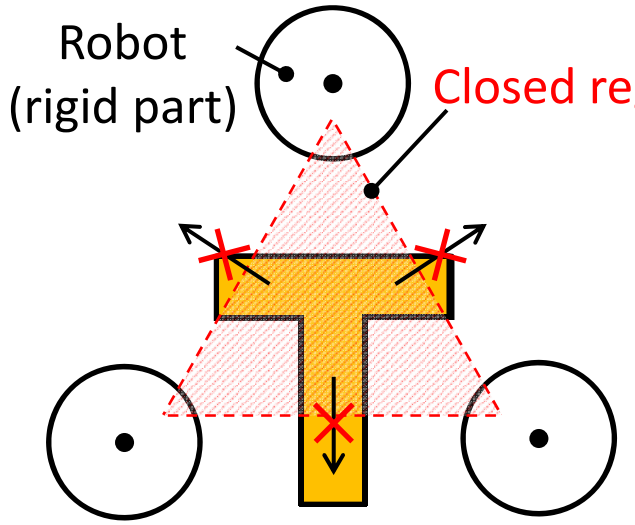
- We need conditions of caging-based grasping in a concrete form for each combination of a robot hand and an object
- Sufficient conditions were derived
- Example: 2D grasp of a T-shaped object by three circular robots



Sufficient condition for 2D caging-based grasping of a T-shaped object (1/2)

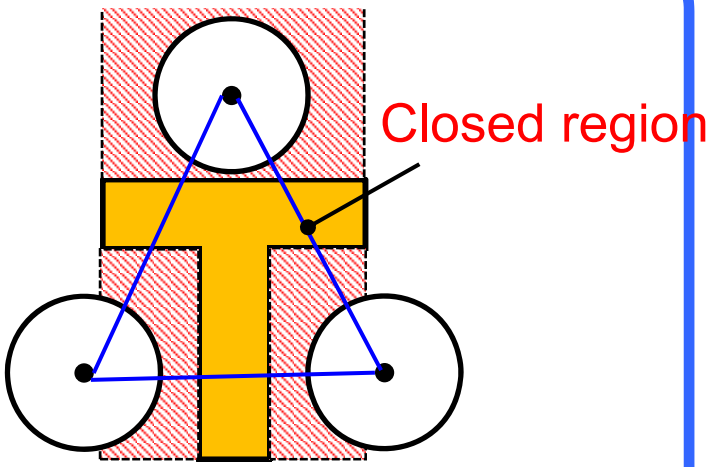
Rigid-part caging condition

Closed region formation



Inter-robot distance must be upper-bounded

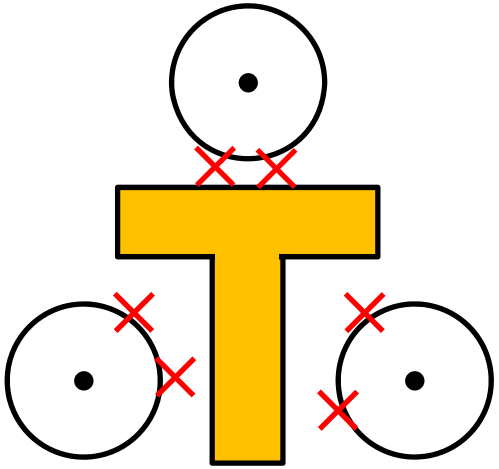
Object inside



The robots must be in each of the shaded regions

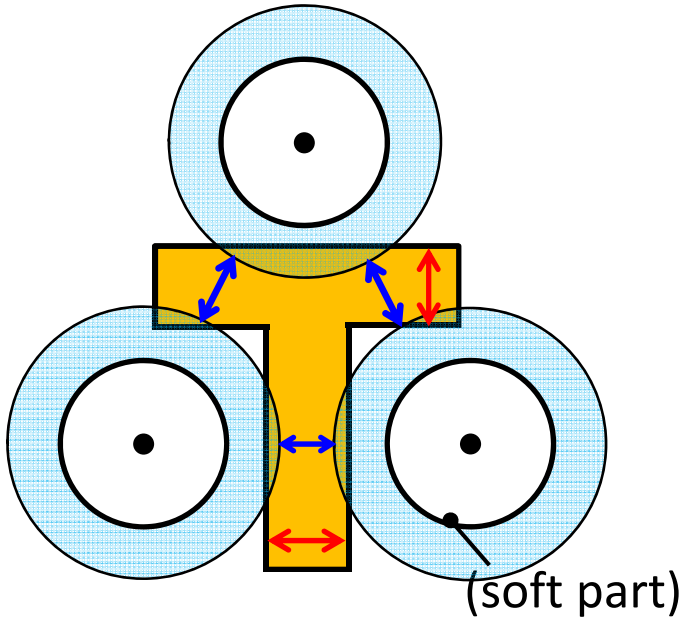
Sufficient condition for 2D caging-based grasping of a T-shaped object (2/2)

No interference



(checked by a collision detection library)

Soft-part deformation condition



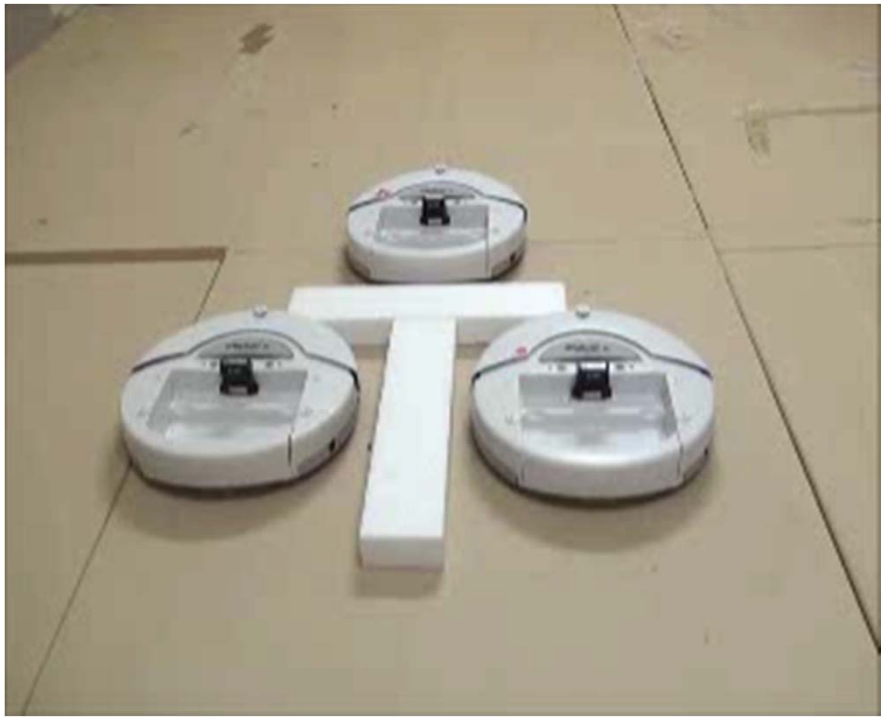
Gap between the soft parts

∧

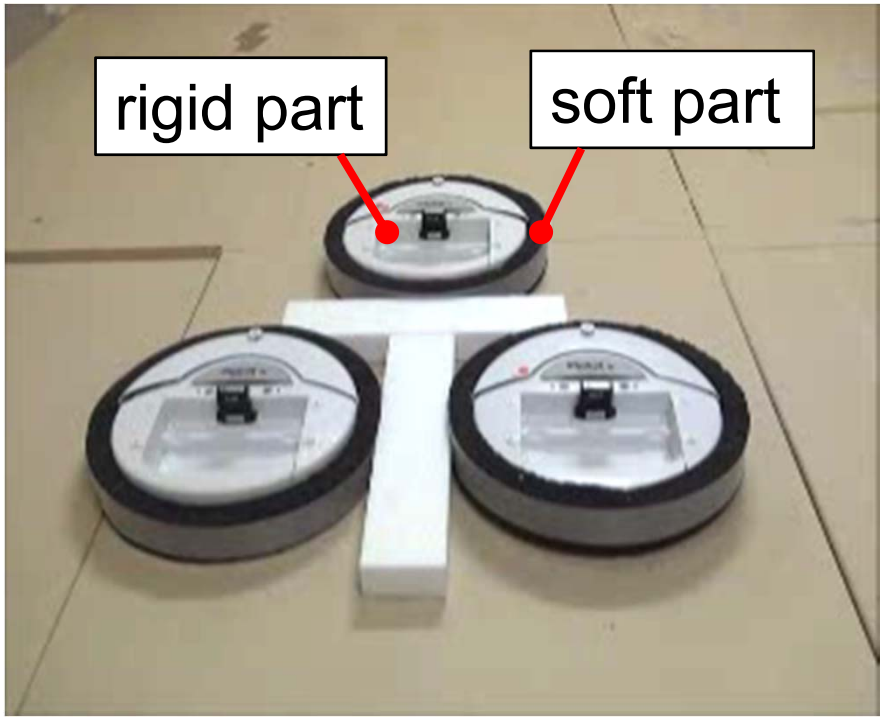
Width of the T-shaped object

Experiments of 2D caging-based grasping by circular robots

- iRobot Create covered with polyurethane foams
- Moving the robots concurrently by open-loop control

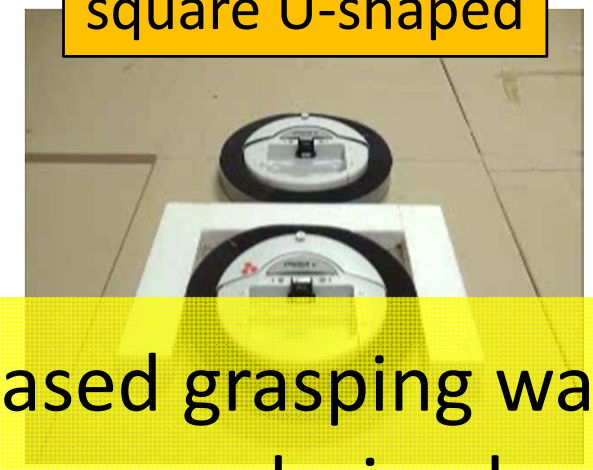


conventional caging

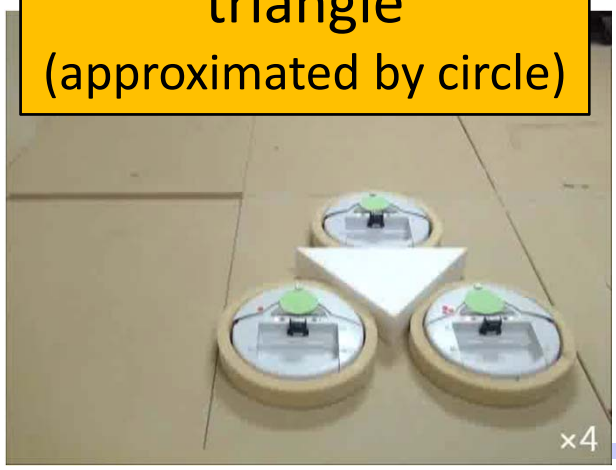


caging-based grasping

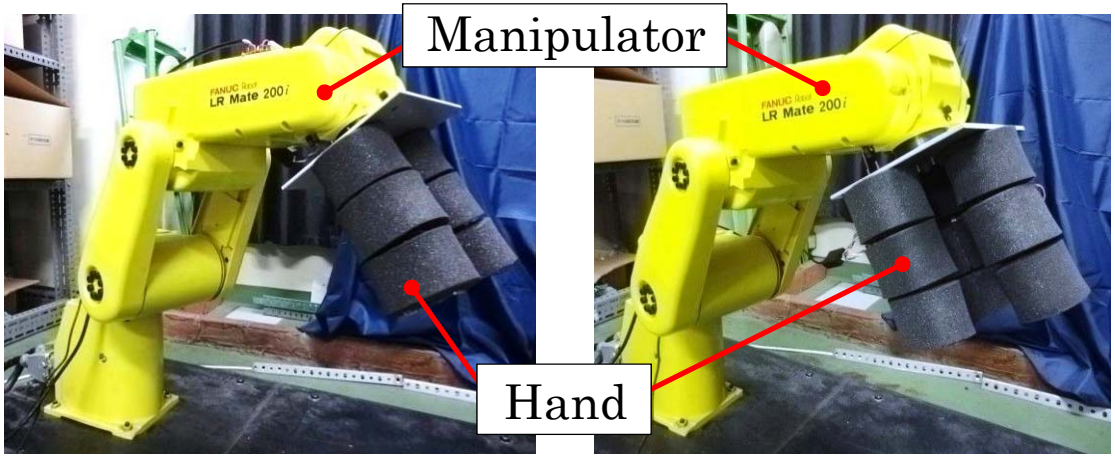
Experiments of 2D caging-based grasping of objects in various shapes



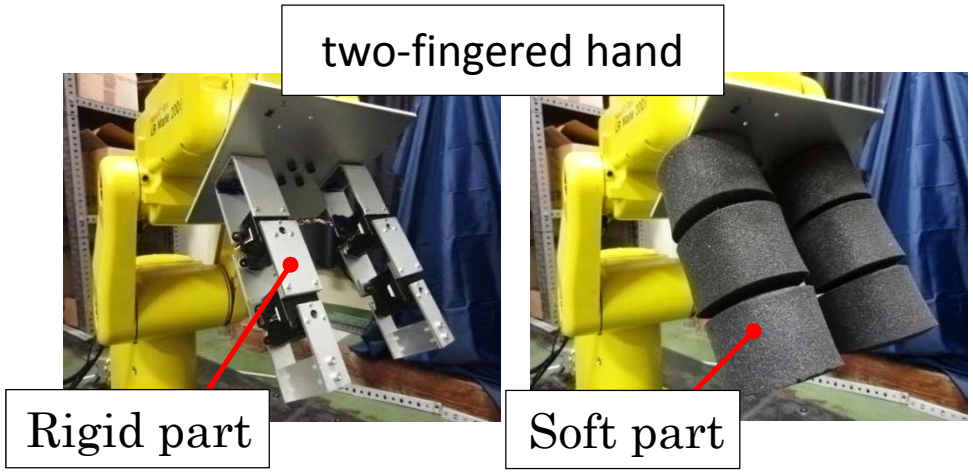
Caging-based grasping was achieved based on our derived conditions

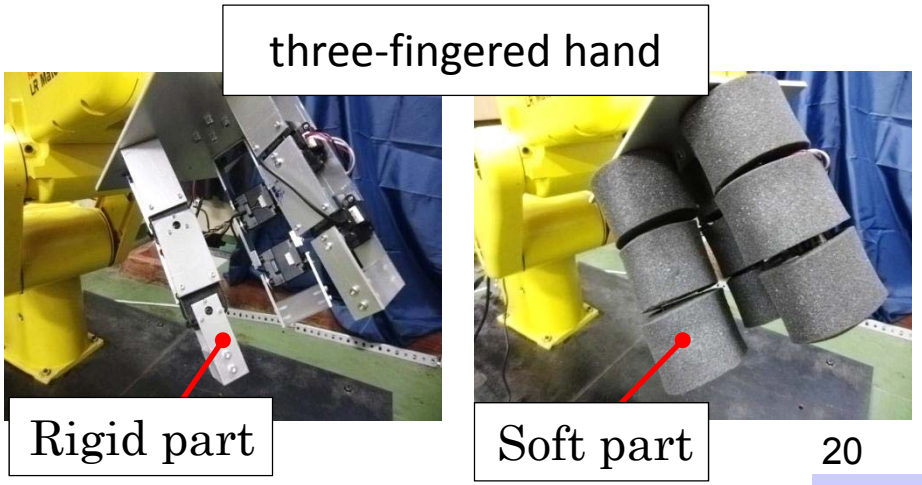


Experimental setup of multifingered articulated hands



- 6-DOF Manipulator
  (Fanuc LR Mate 200i)
- Articulated hand
  Two or three 2-DOF fingers
  Soft parts: urethane foam

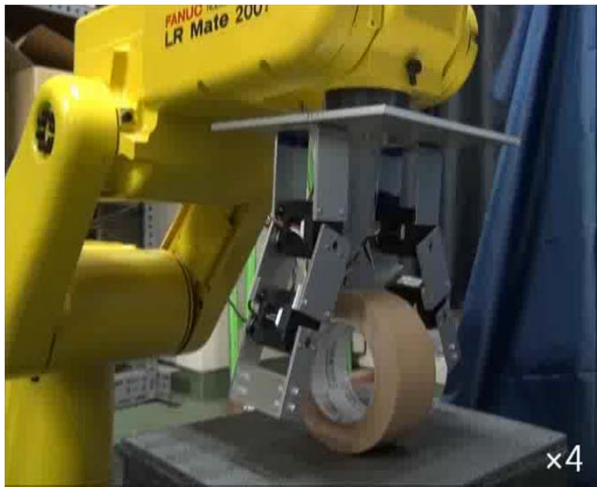




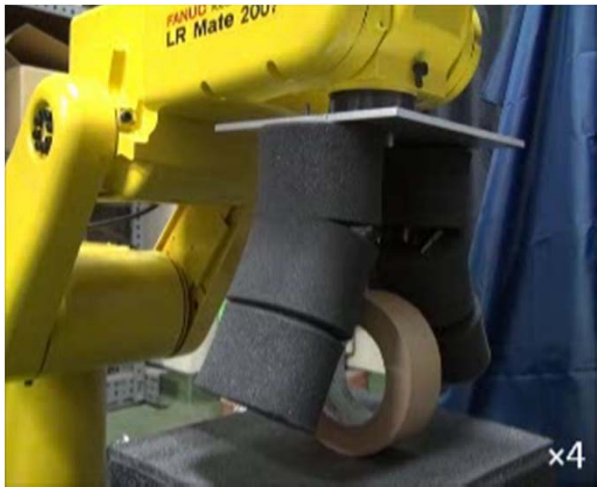
Experiments of 3D caging-based grasping by articulated multifingered hands

conventional caging

caging-based grasping



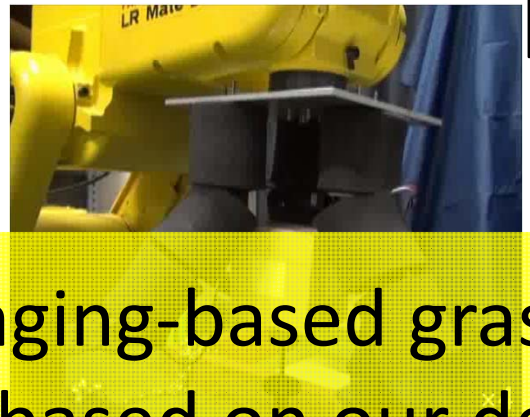
hollow cylinder



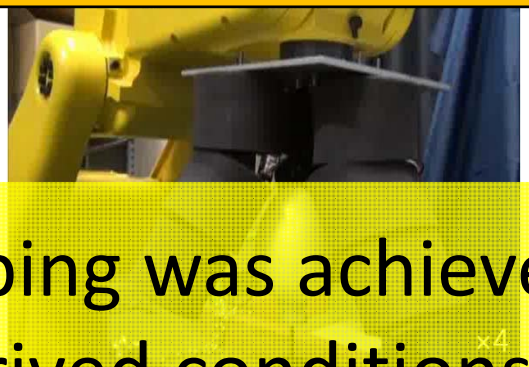
solid cylinder

Experiments with articulated multifingered hands

cuboid



egg-shaped
(approximated by sphere)



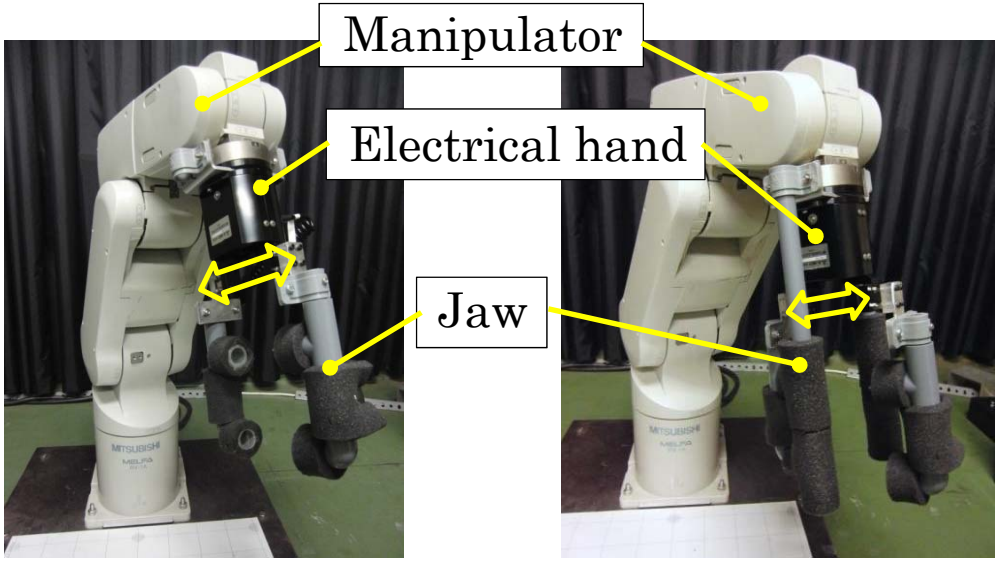
Caging-based grasping was achieved based on our derived conditions

torus

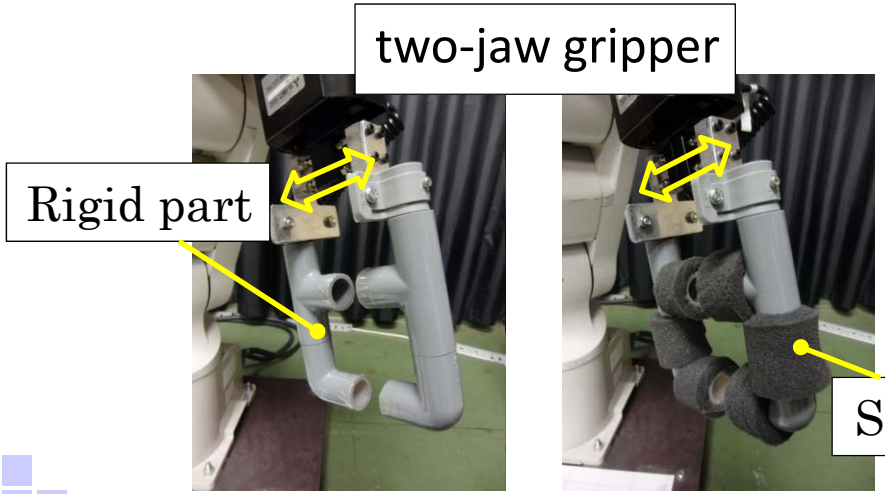
dumbbell-shaped

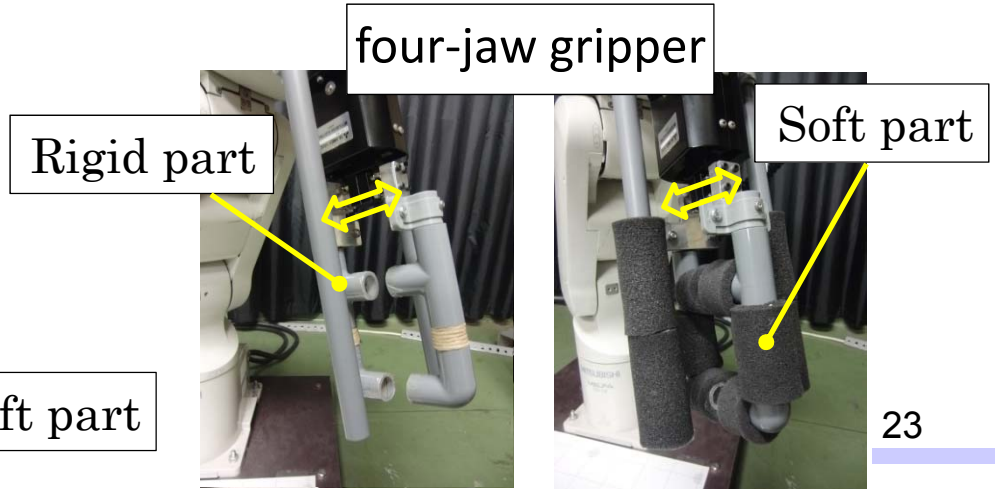
bulb-shaped
(sphere + cylinder)

Experimental setup of multi-jaw grippers



- 6-DOF manipulator
  (Mitsubishi RV-1A)
- 1-DOF gripper
  (Mitsubishi 4A-HM01)
- Rigid parts: PVC pipes
- Soft parts: polyurethane foam





Experiments with multi-jaw grippers

conventional caging

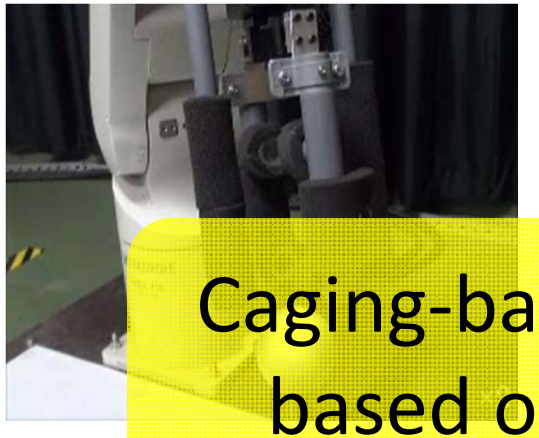
caging-based grasping

torus

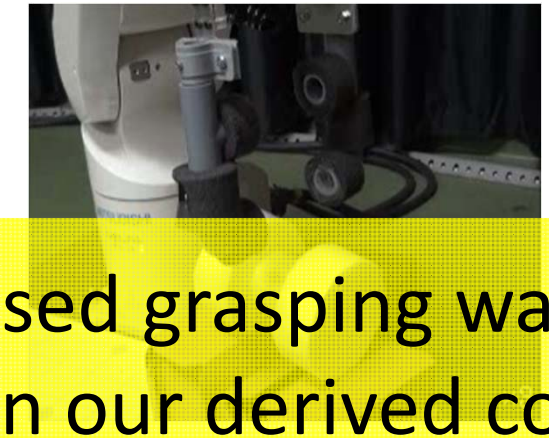
cuboid

Experiments with multi-jaw grippers

sphere



dumbbell-shaped



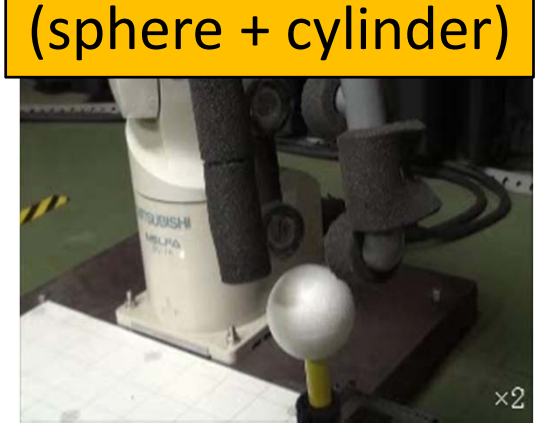
hollow cylinder

Caging-based grasping was achieved based on our derived conditions

solid cylinder

hollow cylinder (bottomed)

bulb-shaped (sphere + cylinder)



Conclusion

- We achieved caging-based grasping of various objects by circular robots, multi-fingered articulated hands and multi-jaw grippers
- Grasping based on only geometrical information is possible using theoretically driven conditions

Future Work

- Stable picking and placing
- How to select appropriate soft parts
- Application to various tasks