Evaluating End-Effectors and System Integration for Warehouse Picking

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Introduction

The Problem

- Cluttered and small workspace
- Poor visibility
- Objects vary widely based on size, shape, surface texture and weight

Solution

- Multiple end-effectors, good at picking various items

Hardware Setup

- Dual-arm Yaskawa Motoman SDA10F Robot 7-DoF per Arm + 1 DoF for Torso
- 2 different end-effectors on each hand
- Kiva Systems shelf as used in the Amazon Picking Challenge
- RealSense 3D camera
- Vacuum Sources

Hardware Setup – RightHand Robotics ReFlex Hand

Pros:

- Rubber fingers provide good friction
- Strong servo motors for heavy items (<5lb)
- Ability to execute caging grasps
- Built in pressure sensors allow for easy grasp validation

Cons:

- Even though compact relative to other similar hands, it is still large
- Hard to plan for

Hardware Setup – Vacuum Sources

High Vacuum (< -95kPa), Low Flow	Low Vacuum (~-12kPa), High Flow

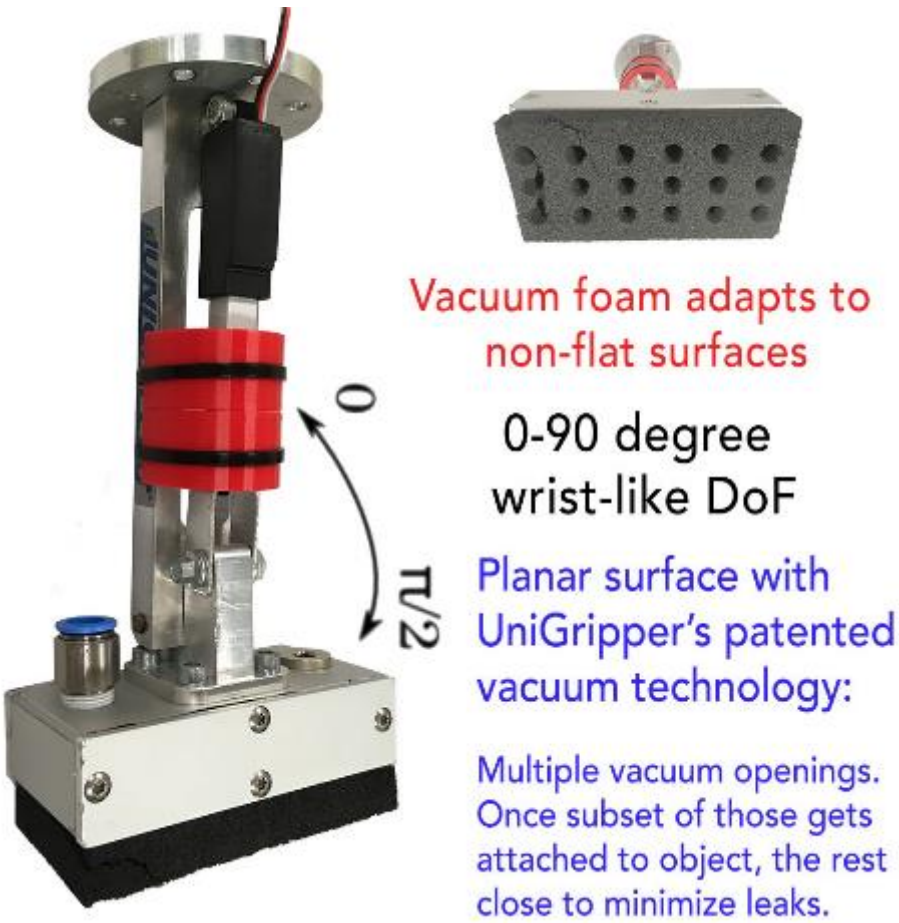
Pros:
• High vacuum strong suction/lifting force, great for heavy objects (good seal and no leaks assumed, i.e. smooth continuous surfaces)
• Allows for smaller suction cups (good in tight spaces)
	Pros:
	• Inexpensive vacuum source (e.g., vacuum cleaner)
	• Good tolerance to vacuum leaks
	  • Works on uneven surfaces as well as porous materials (e.g., fabrics)
	  • Precise positioning not as important (easier planning)

Cons:
• Expensive (air ejectors, air compressor, etc)
• Even small leaks can affect grasp robustness
  • Not good for uneven surfaces
  • Requires precise placement if smooth surfaces are limited
  • Will not work on porous materials
	Cons:
	• Weaker suction/lifting force, can be problematic for heavy objects
	• Requires larger vacuum opening (e.g. suction cup) to accommodate the high air flow;

Air Compressor Feeding Air Ejector

6hp Dry/ Wet Shop Vac

Hardware Setup – High Vacuum/Low Flow – Custom End-Effector by Unigripper



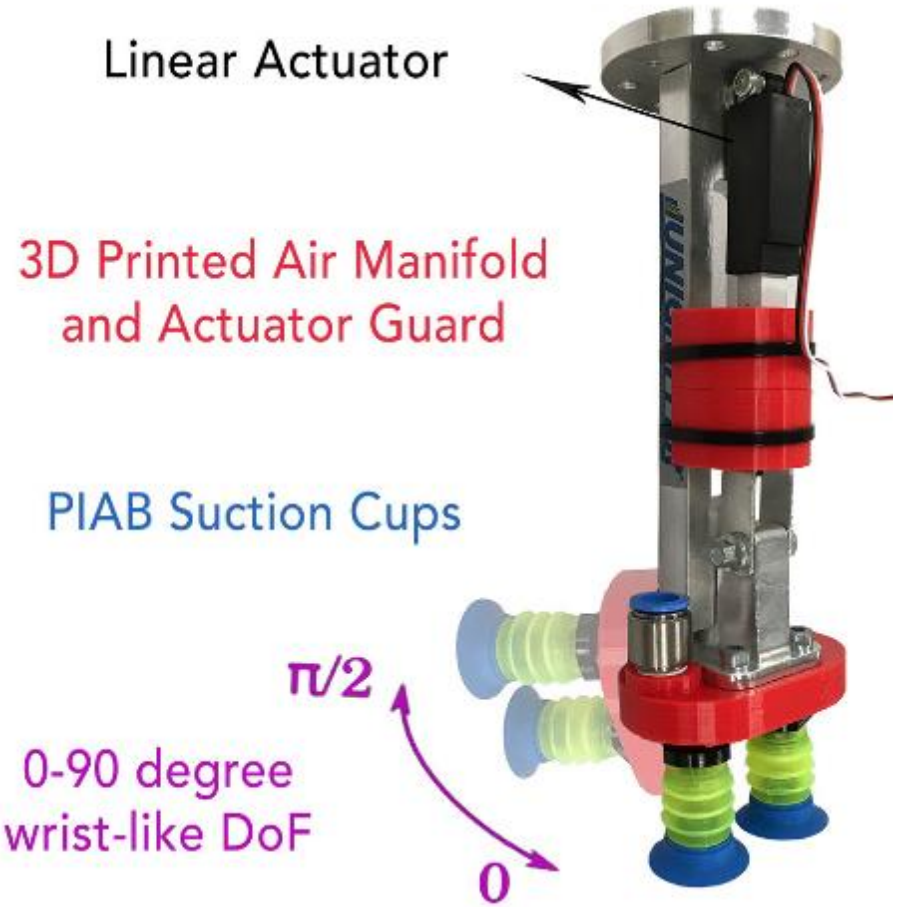
Pros:

- Wrist-like DoF allows approaching object from the front and from the top
- Maintains grasp even if a large number of the openings are unconcluded by the object (vacuum leak)

Cons:

- The presence of vacuum foam and the low flow of UniGripper's vacuum technology required the gripper to be pressed against the object in order to attach itself. Objects grasped from the front can easily topple over

Hardware Setup – High Vacuum/Low Flow – Custom End-Effector by Unigripper (Modified)



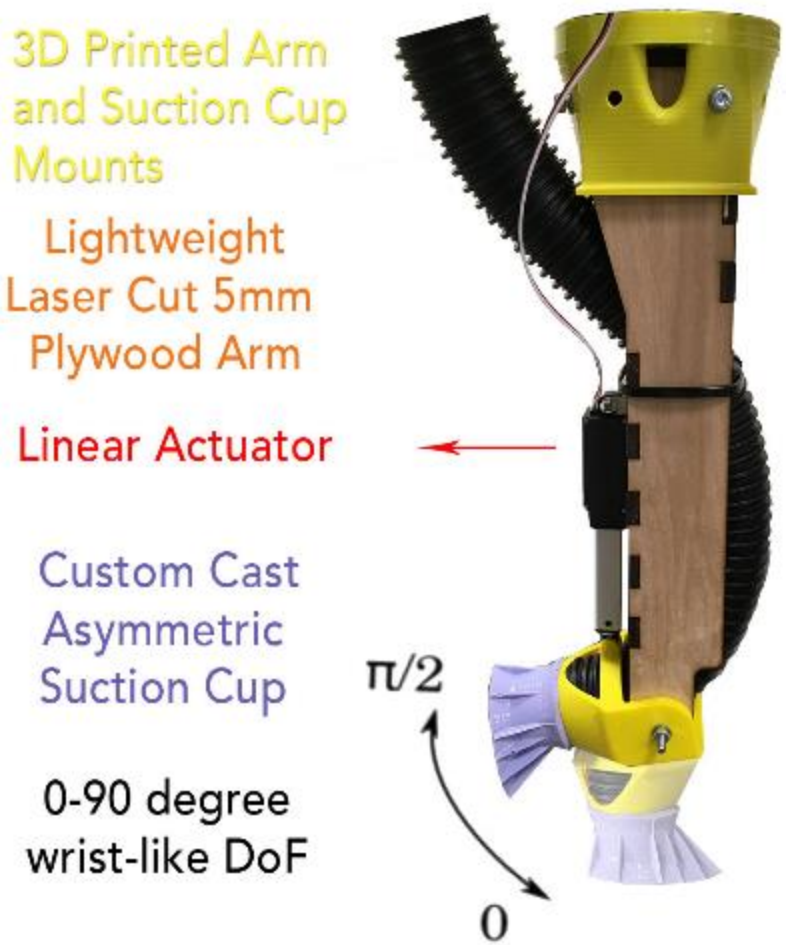
Pros:

- DoF allows approaching object from the front and from the top
- 2 suction cups vs array of openings greatly increases the suction force produced (objects attach to end-effector much easier)
- More compact compared to UniGripper's vacuum solution

Cons:

- More accurate planning is required as good seal is needed at **Both** suction cups. Leaving one open is a very large vacuum leak.

Hardware Setup – Low Vacuum/High Flow – Custom End-Effector Designed and Built In-House



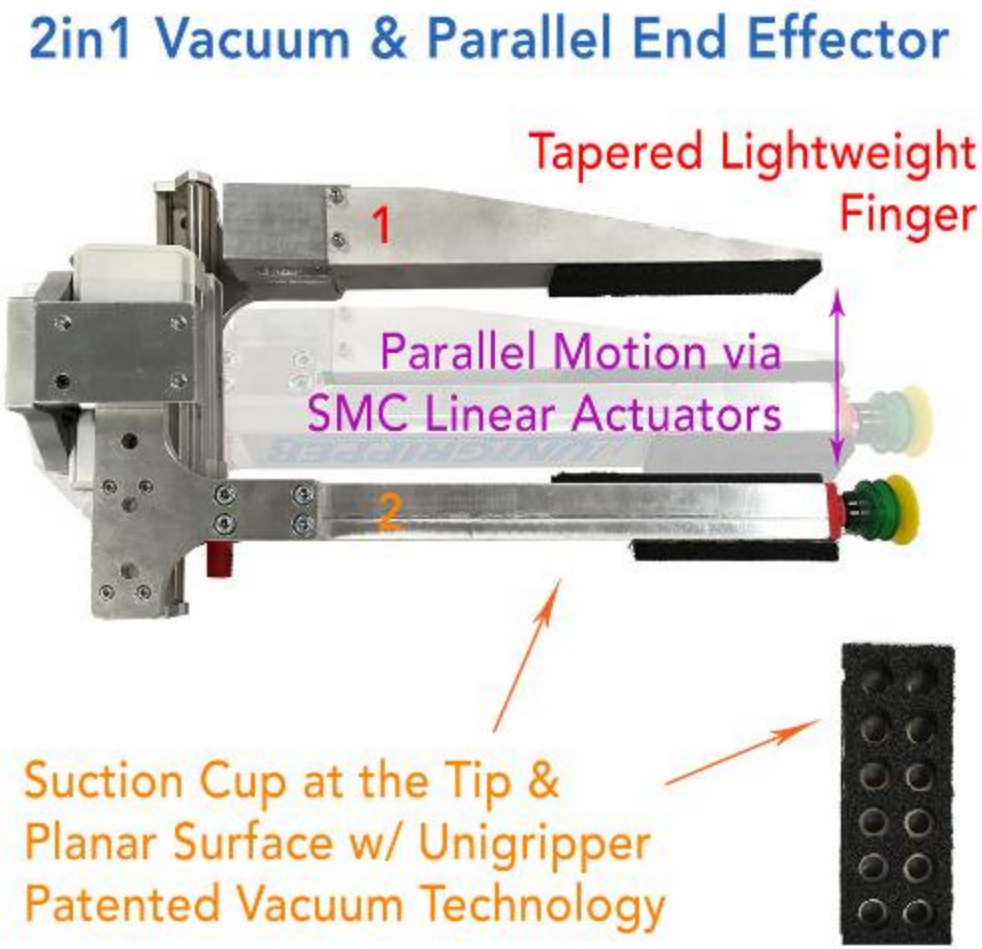
Pros:

- Much higher air flow can tolerate very large leaks and works with uneven and porous objects, requiring less precise planning
- Asymmetric cup provides secure horizontal grasps while keeping overall cup diameter small
- DoF allows approaching object from the front and from the top

Cons:

- High flow requires a thick hose and large suction cup, which limits the minimum size of gripper achievable

Hardware Setup – Low Vacuum/High Flow – Unigripper Hybrid Gripper



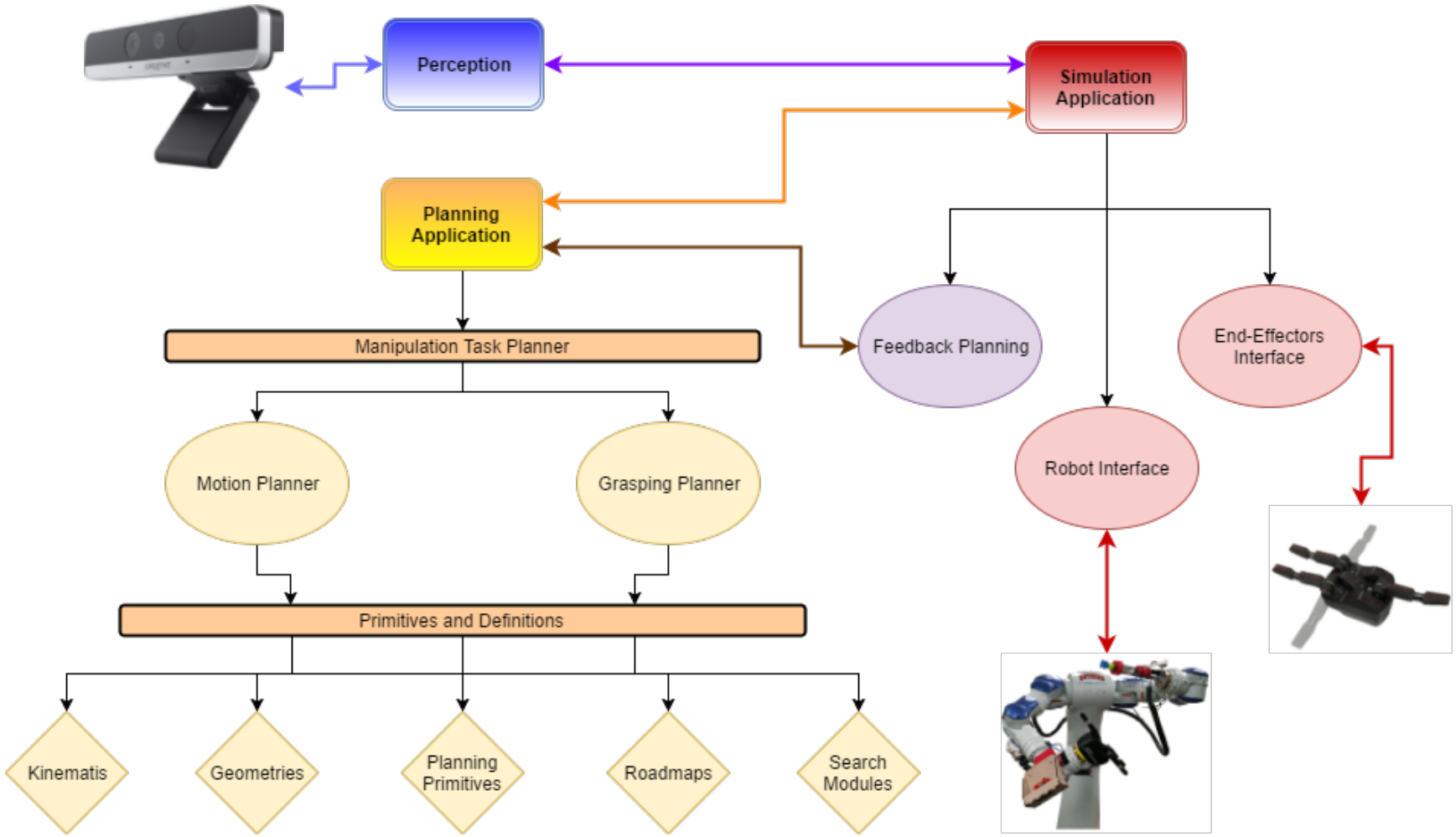
Pros:

- Suction cup at the tip allows reaching in tight spaces and attaching to lighter objects securely
- UniGripper planar surface allows grasping flat objects
- Relatively thin Parallel fingers allow for reaching deep inside bin.
- Strong parallel motors allow grasping of heavy objects

Cons:

- Large size due to UniGripper vacuum technology, long fingers and need to pick heavy objects (large motors required)

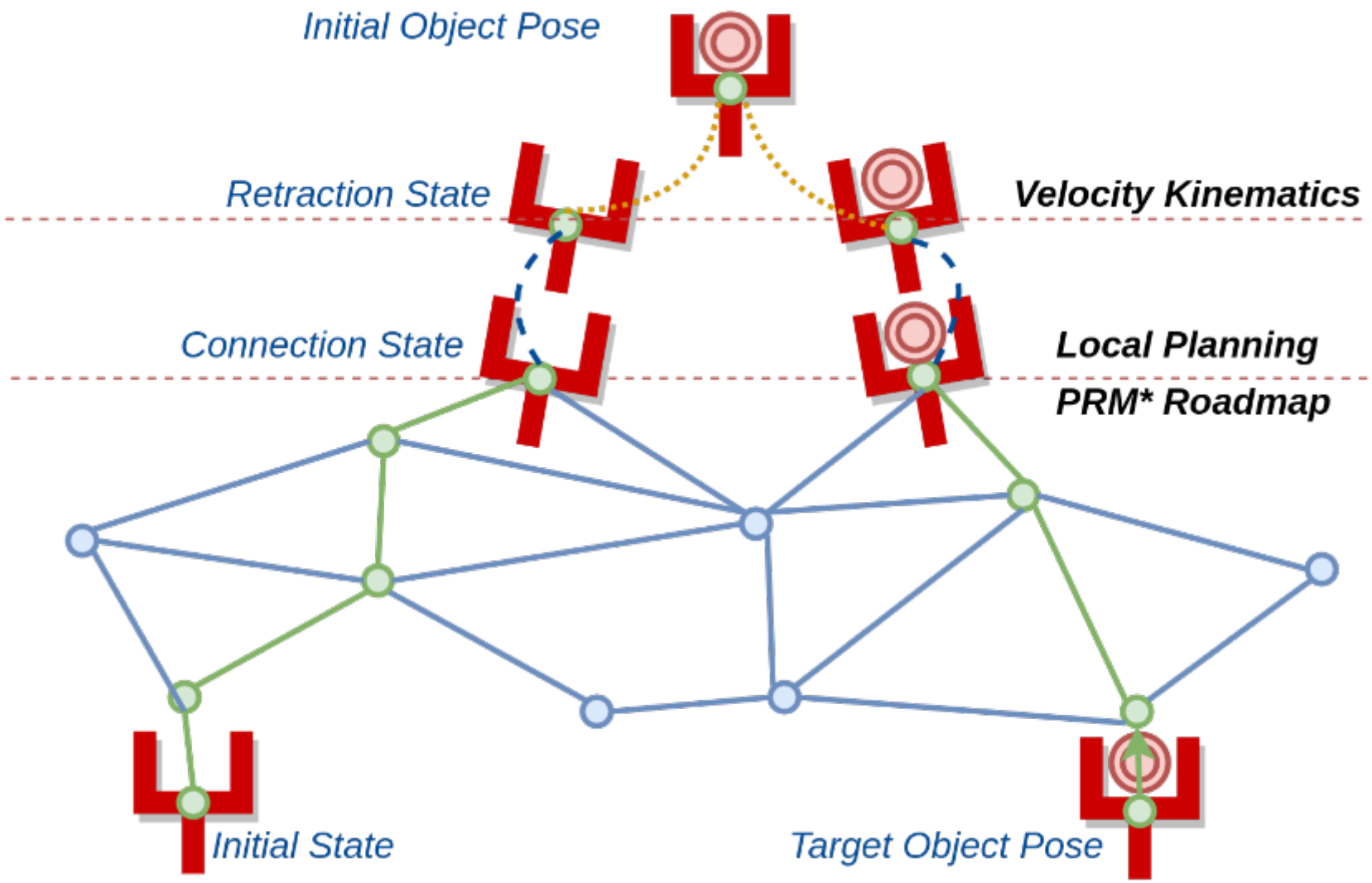
System Integration – Software Architecture



System Integration – Perception

- PRACSYS group proposed a perception solution using Regions with Convolutional Neural Network (R-CNN)
- A dataset of RGB-D images of all the APC objects is available in http://pracsyslab.org/rutgers_apc_rgbd_dataset
- In order to estimate the pose of an object
  - Move the camera to 4 predefined positions
  - Process the RGB-D information from those positions
  - Apply physics to correct the estimate

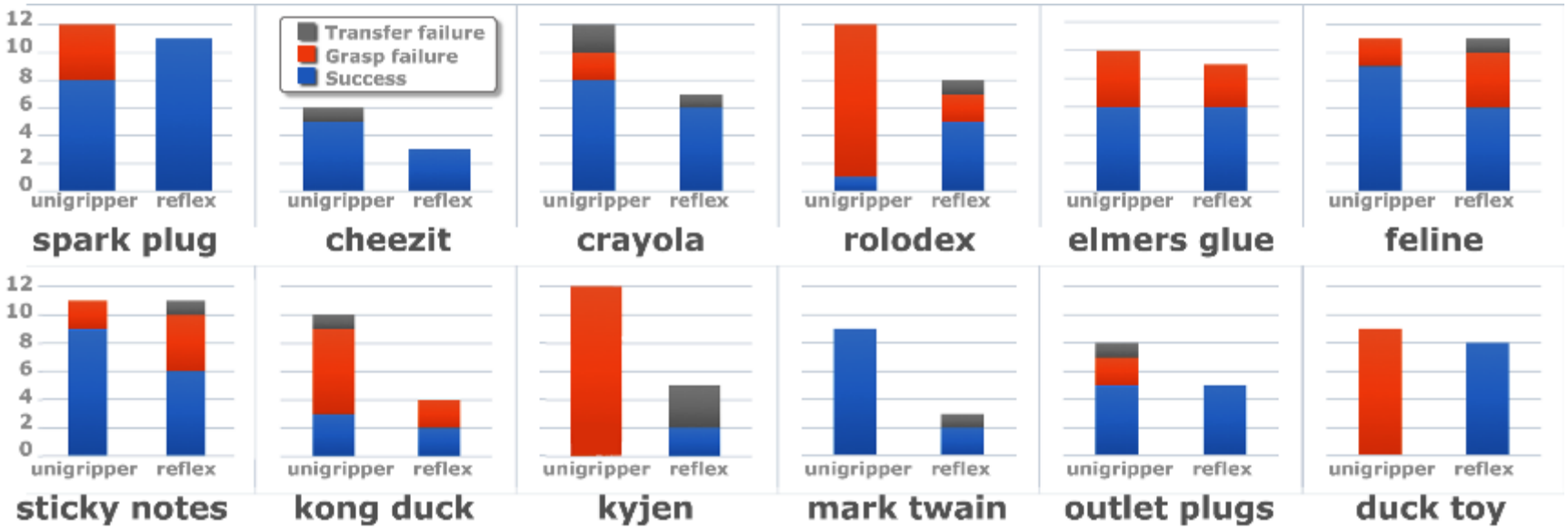
System Integration – Motion Planning Pipeline



System Integration – Grasp Planning

- Create online a set of ***feasible*** grasps
  - Use the end-effector geometry and move it on the graspable surfaces of the object
  - Reject the grasps with insufficient overlap between the end effector and the object surface
- Create a ***valid*** set of grasps
  - Get an IK solution for each grasp in the feasible set
  - Accept all the collision free grasps
- Invoke motion planning to provide a plan that moves the end-effector in one of the valid grasps

Experimental Results – Unigripper Vacuum End-Effector vs ReFlex Underactuated Hand



Conclusions & Future Work

- Dual-arm manipulator is beneficial
- Vacuum end-effectors are compact and very promising
- More work needed on perception and planning
- High-flow vacuum end-effector currently under evaluation
- Hybrid gripper end-effector currently under evaluation
- Currently developing soft-robotics elastomer-based end-effectors to minimize hardware failures and encourage use of machine learning