

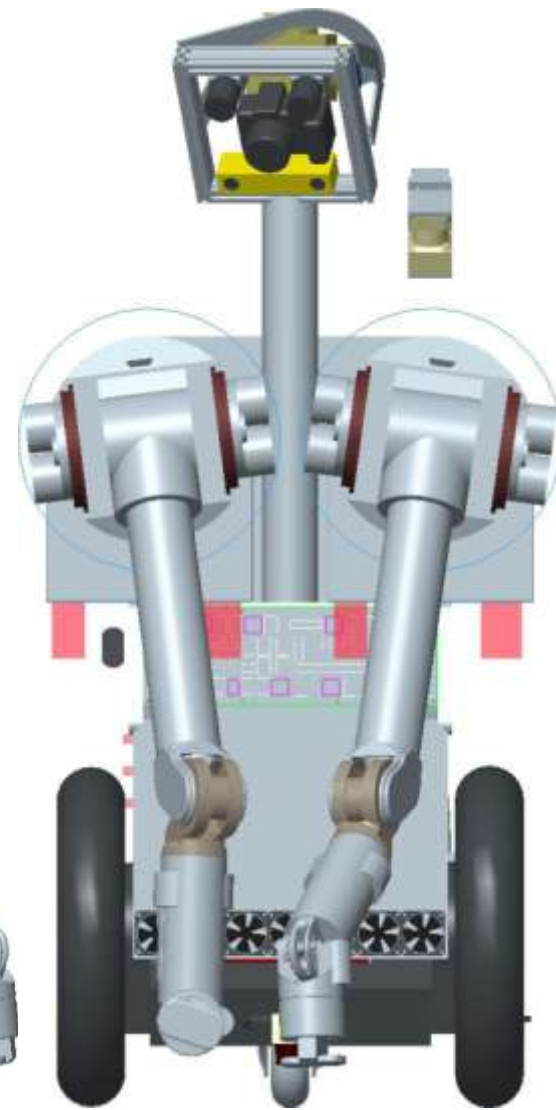
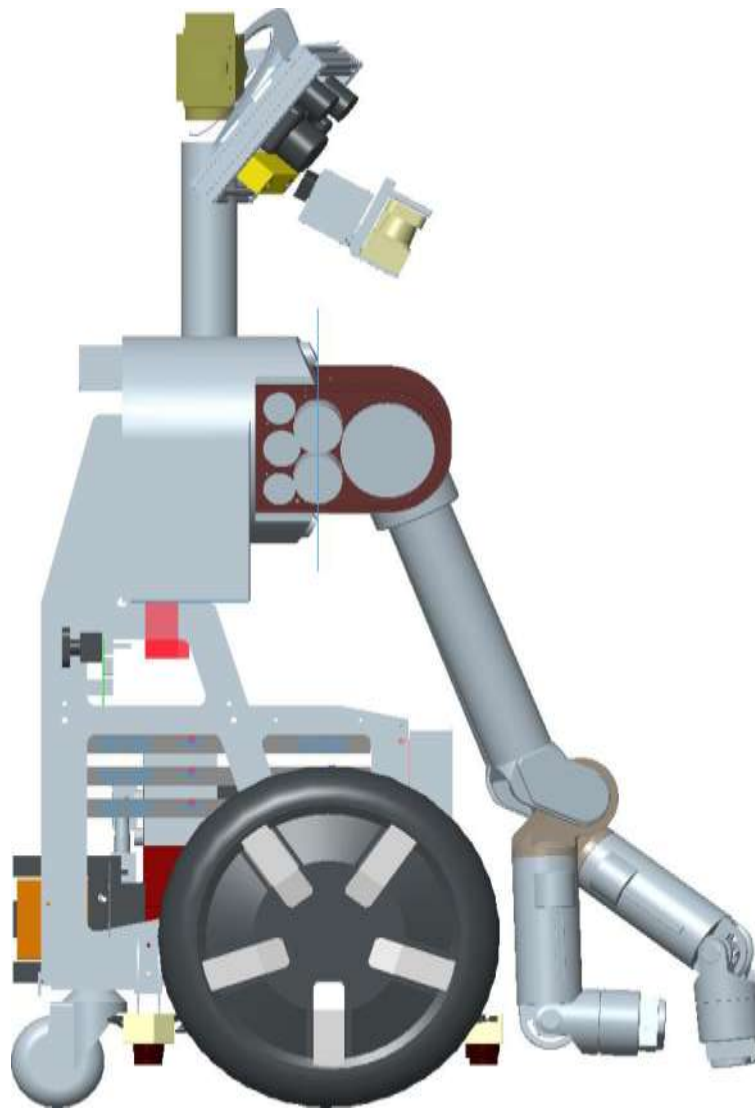
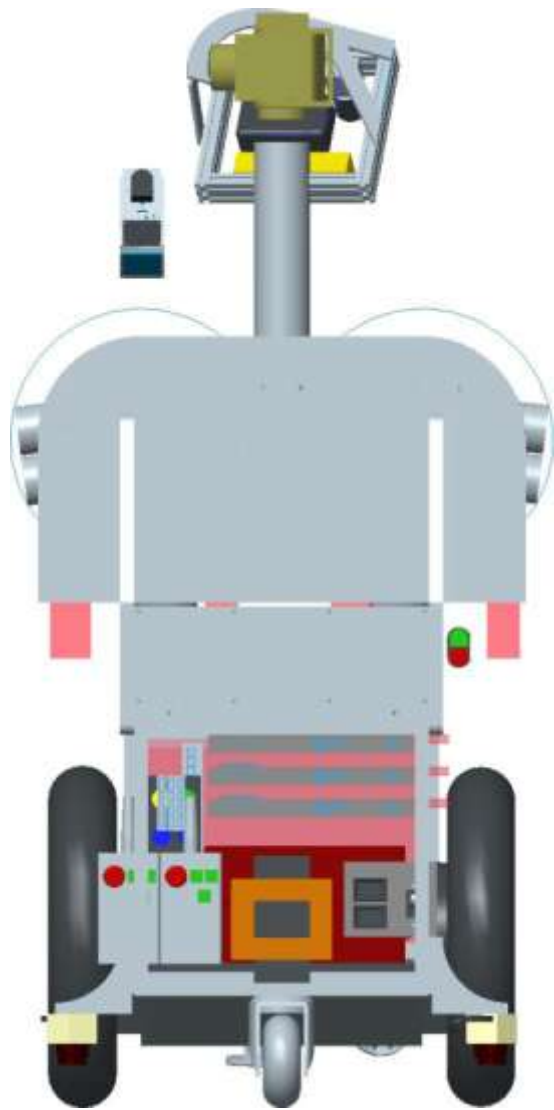
Reconciling Geometric Planners with Physical Manipulation



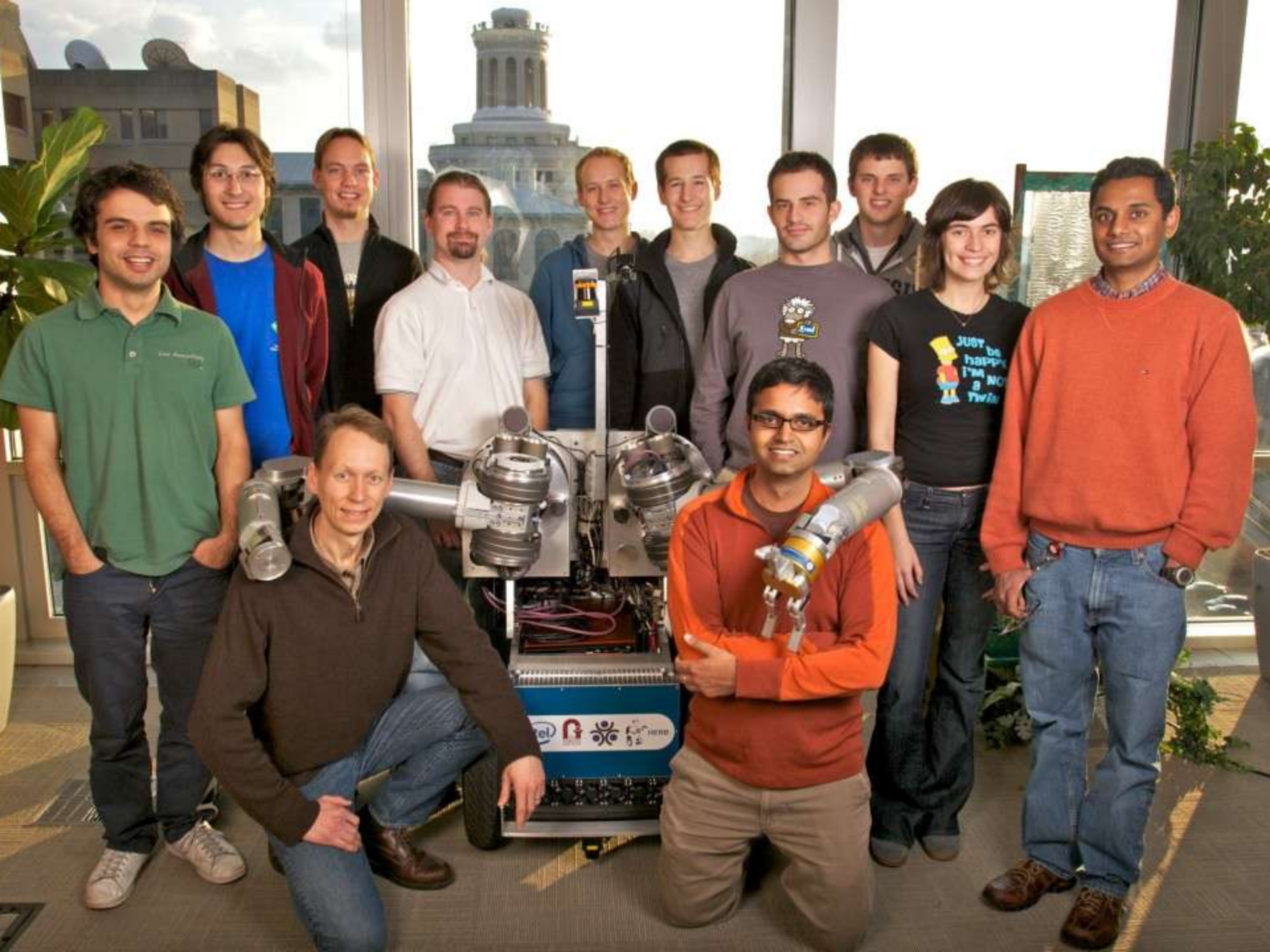
Siddhartha Srinivasa

Associate Professor
The Robotics Institute, CMU
www.cs.cmu.edu/~siddh

Director
The Personal Robotics Lab





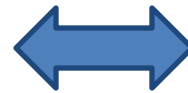




GARRY KASPAROV

DEEP JUNIOR

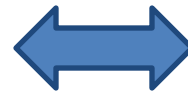
Physical Manipulation



Geometric Search



Physical Manipulation



Geometric Search



Parallelism

Navigation

Learning

Control

Perception

Manipulation

Systems

HRI

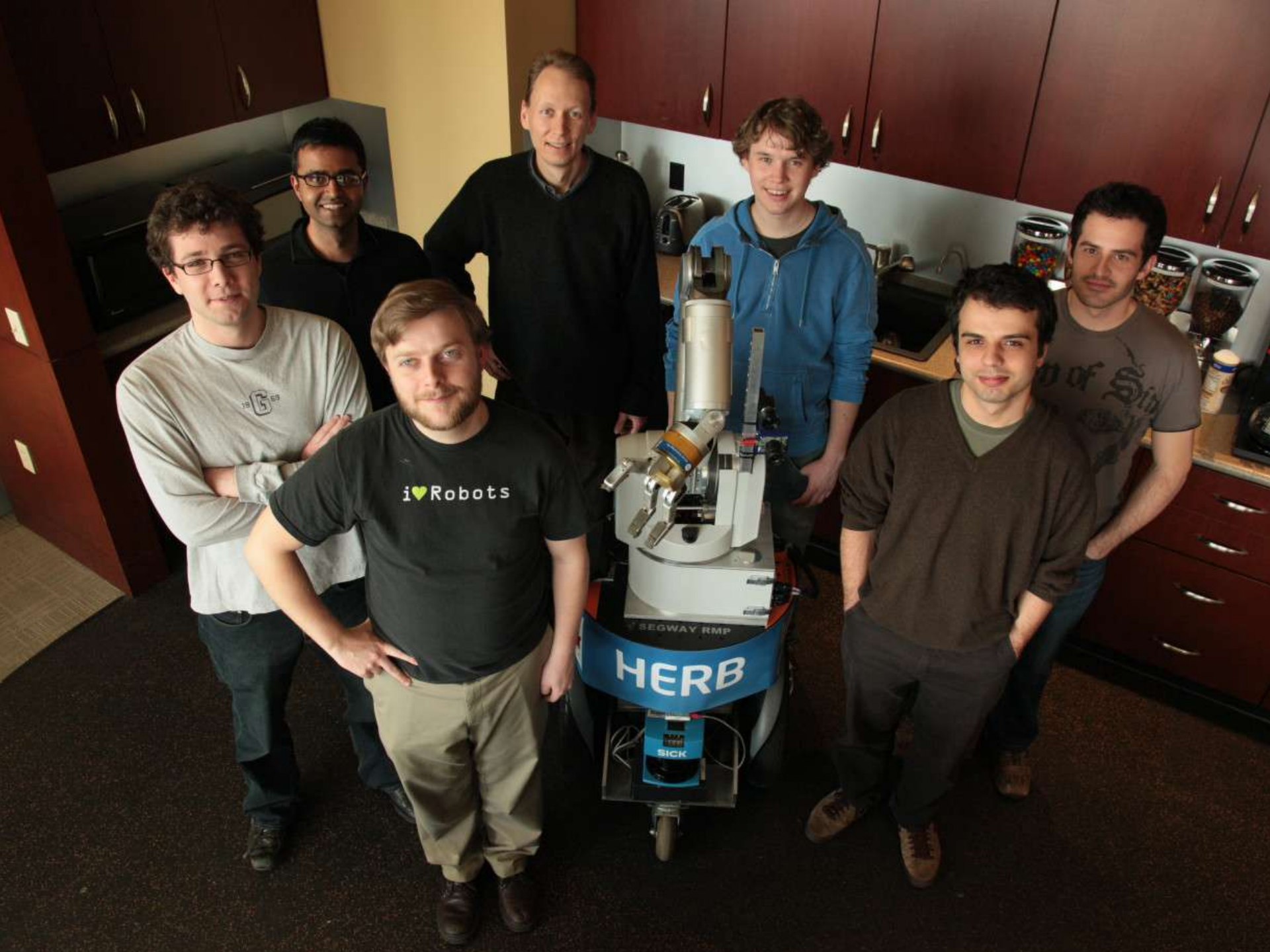
3D Modeling



possible plan
- pipeline
- control
- combine

left $[-928, 3487] 12$
right $[-88, 0-15] 11$



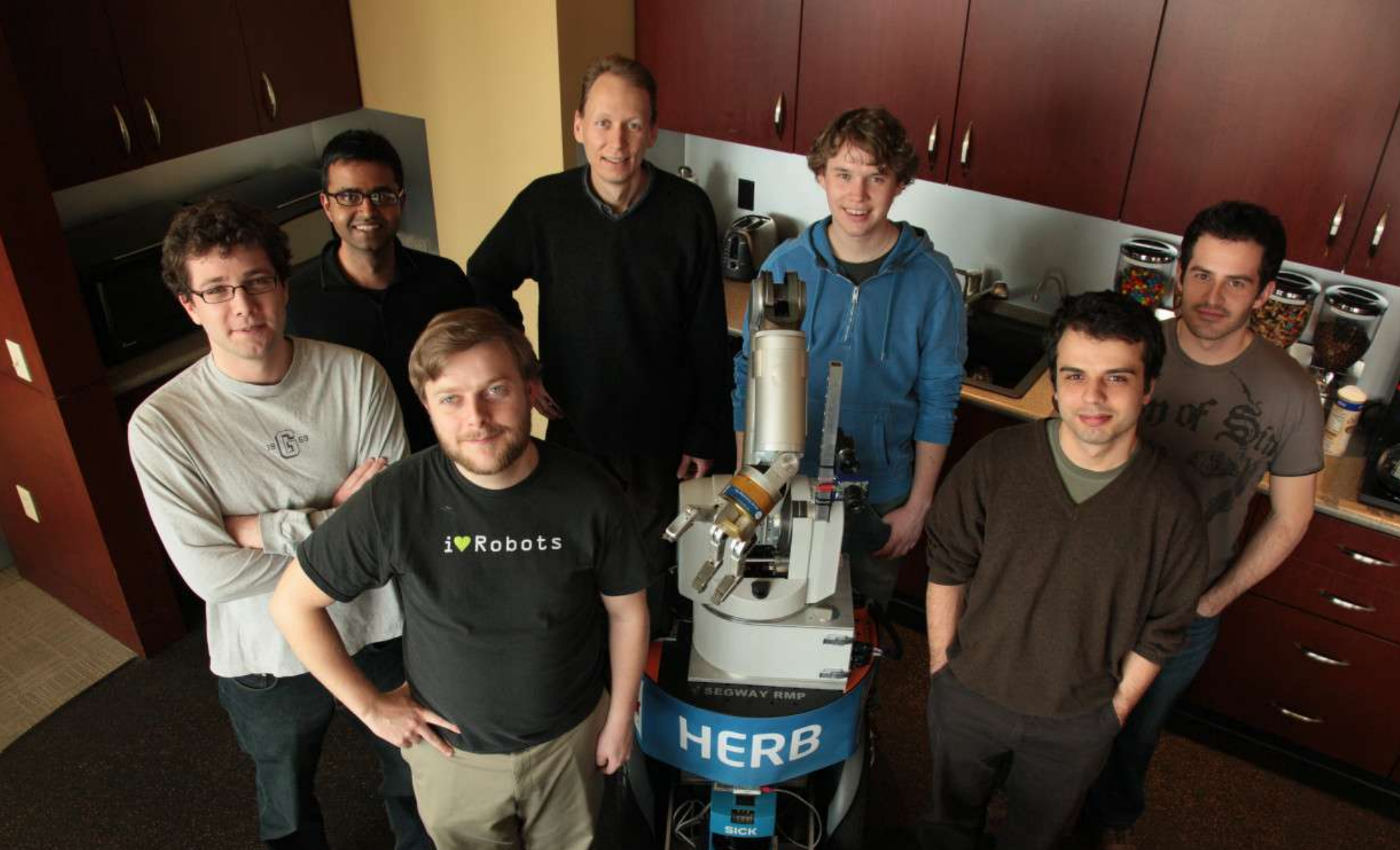


i♥Robots

HERB

SICK

SEGWAY RMP



Manipulation Planning

Constraints



Constraints



Pose

Constraints



Torque

Constraints



Balance

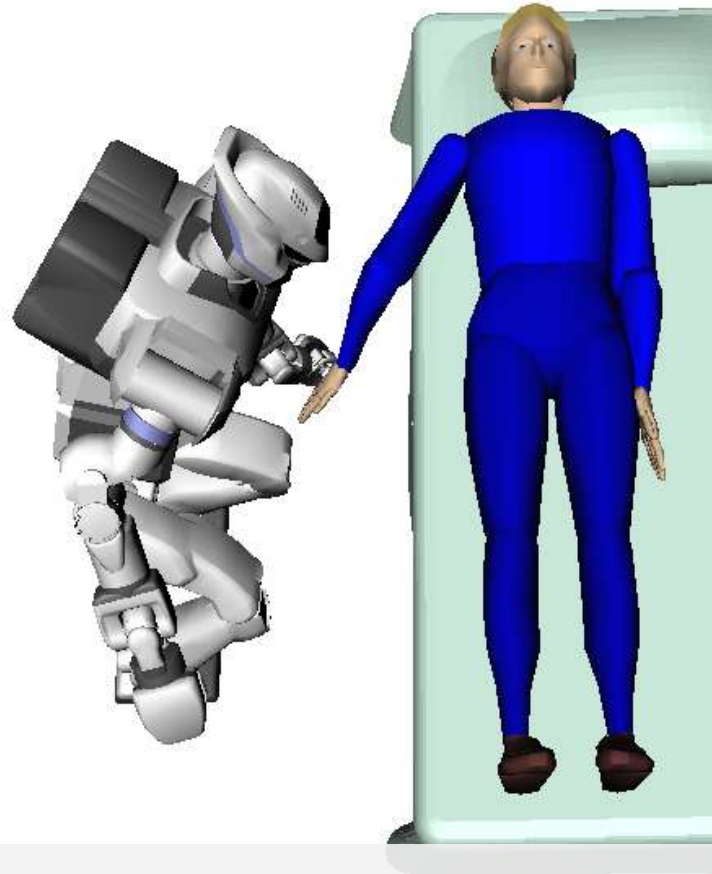


Constraints



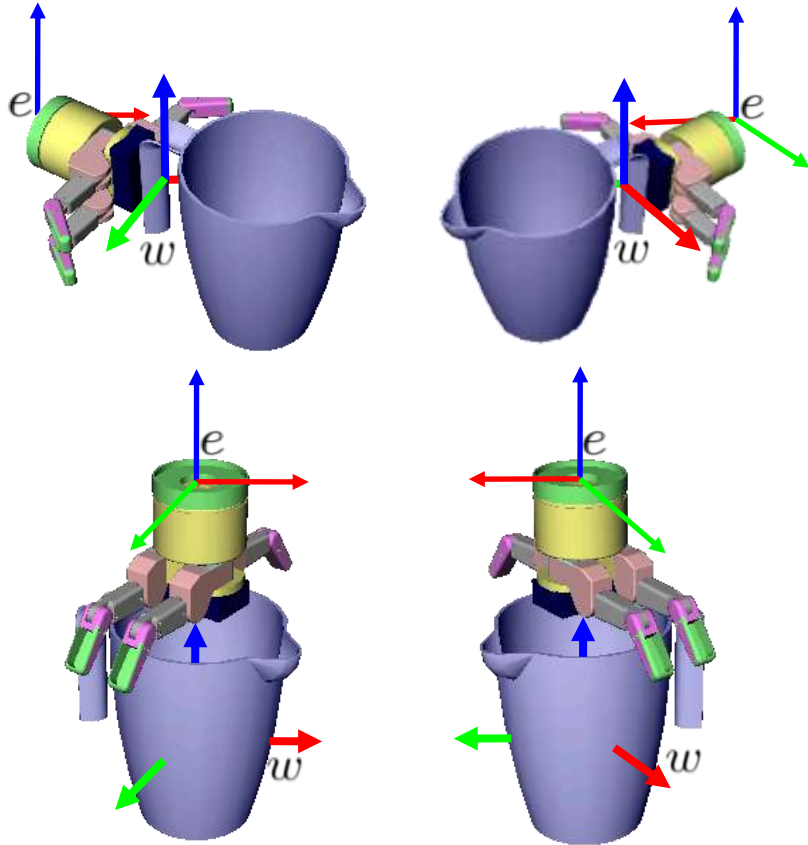
Closed
Chains

Constraints



Underactuation

Affordances

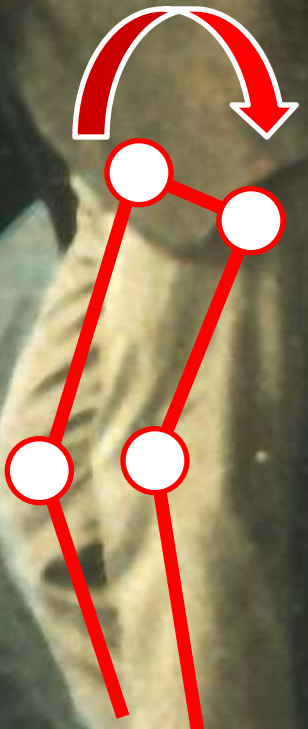


Goal Sets

Affordances



Goal Sets



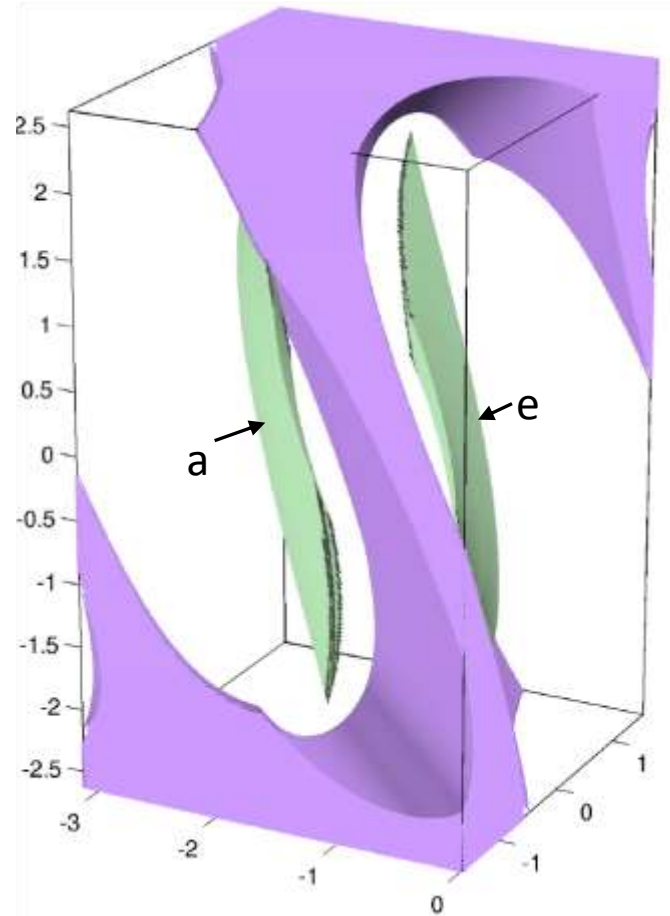
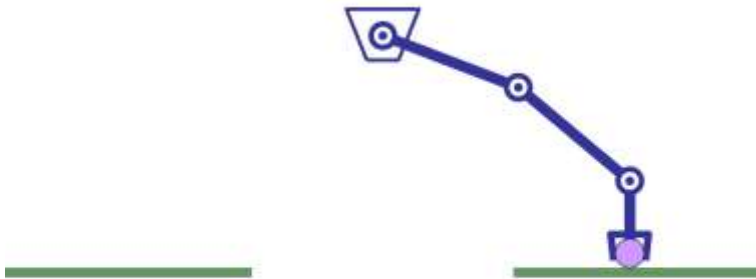
Why is this hard?

Representation

a:



e:

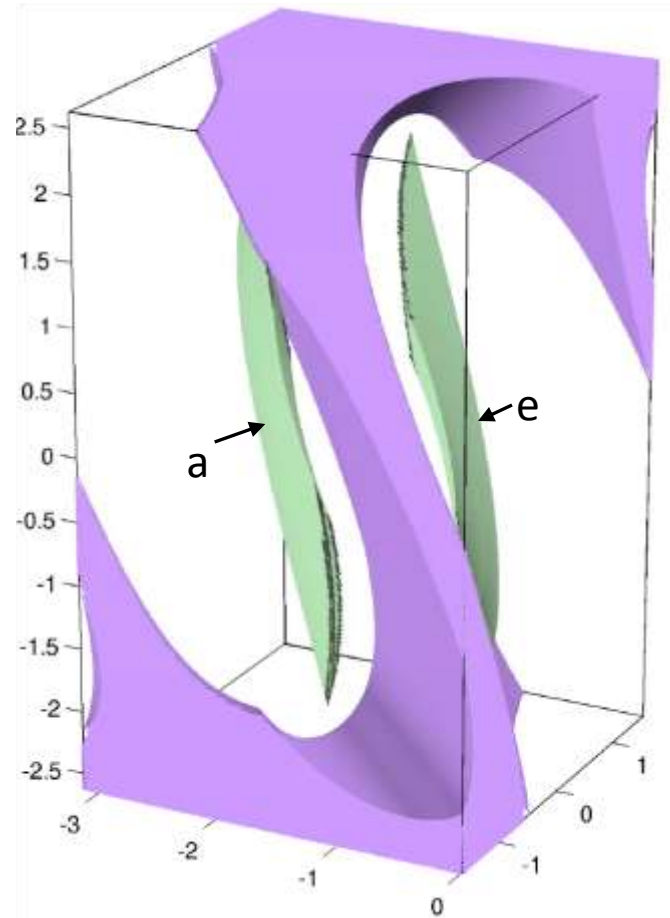
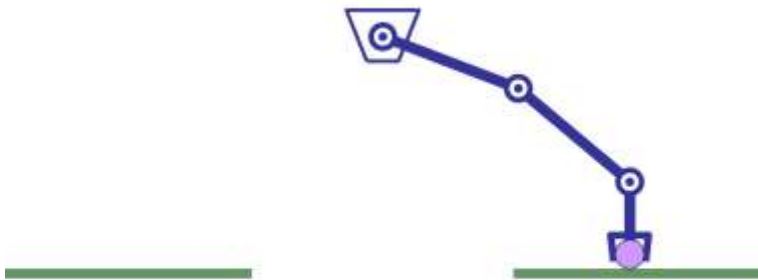


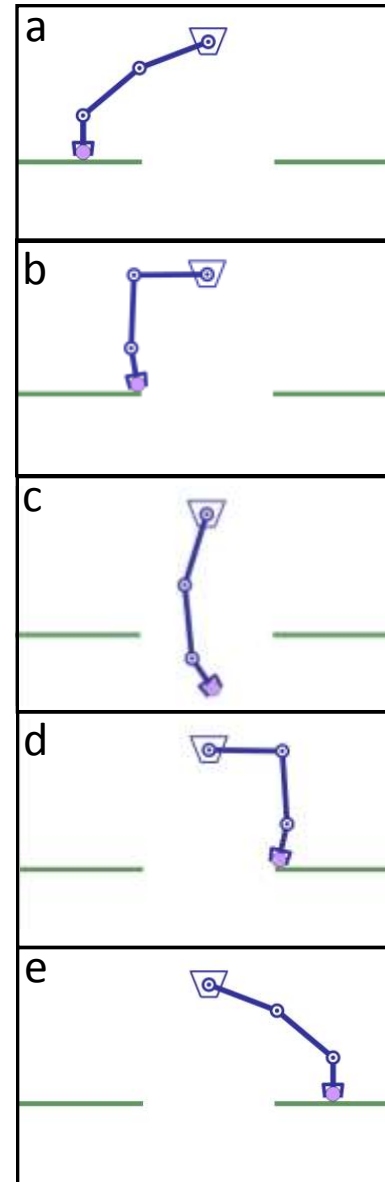
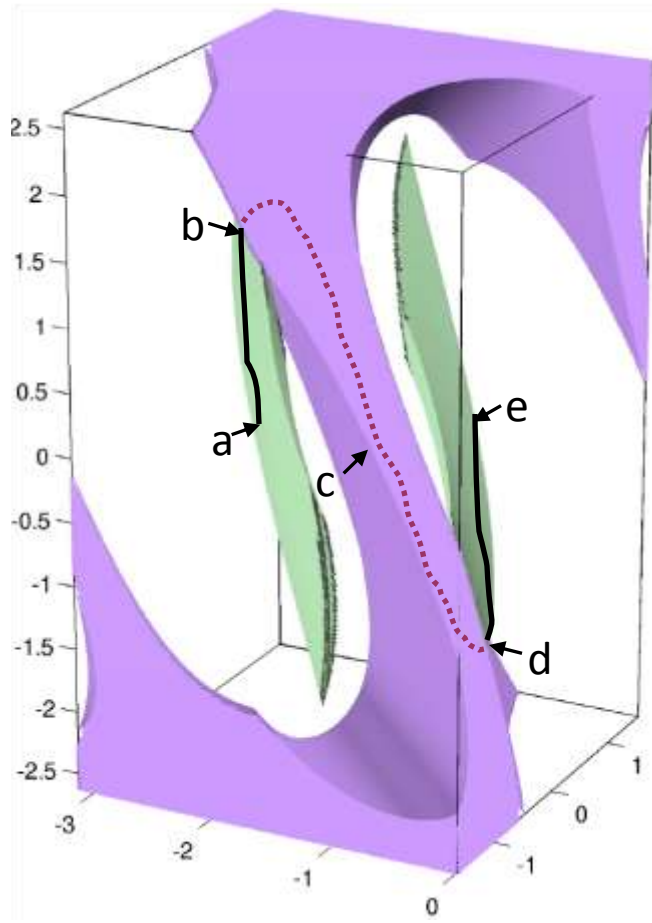
Search

a:



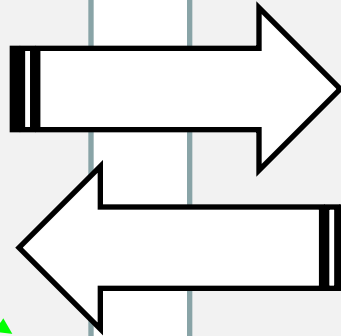
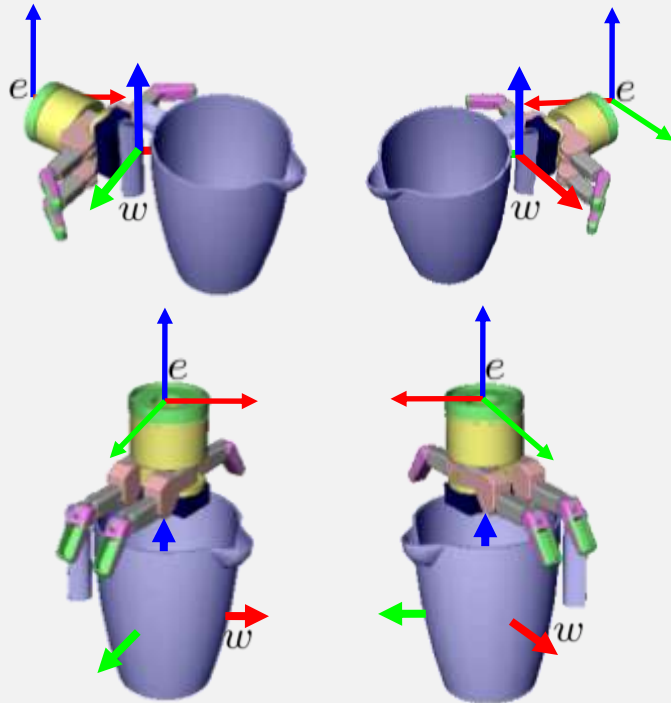
e:



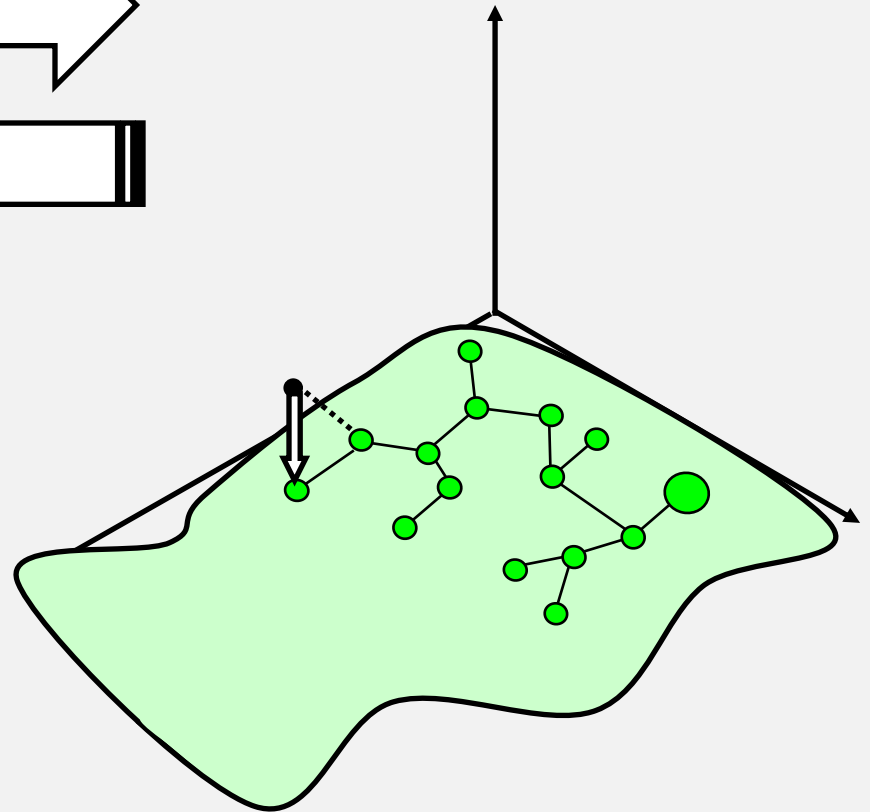


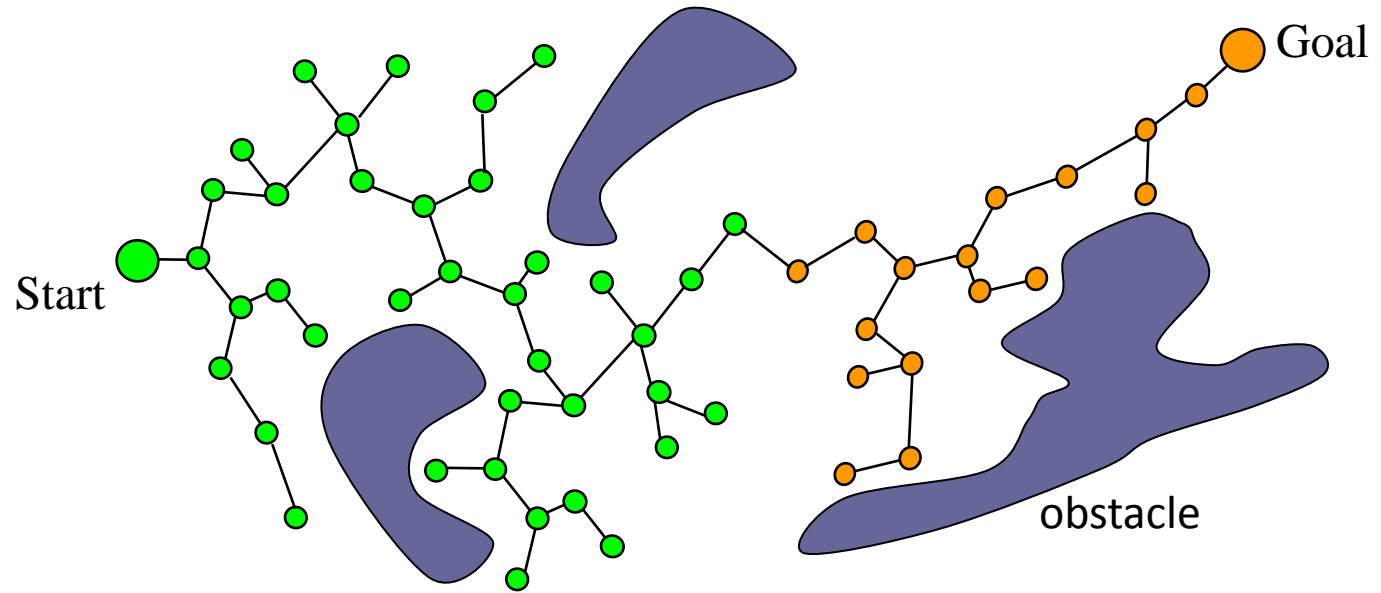


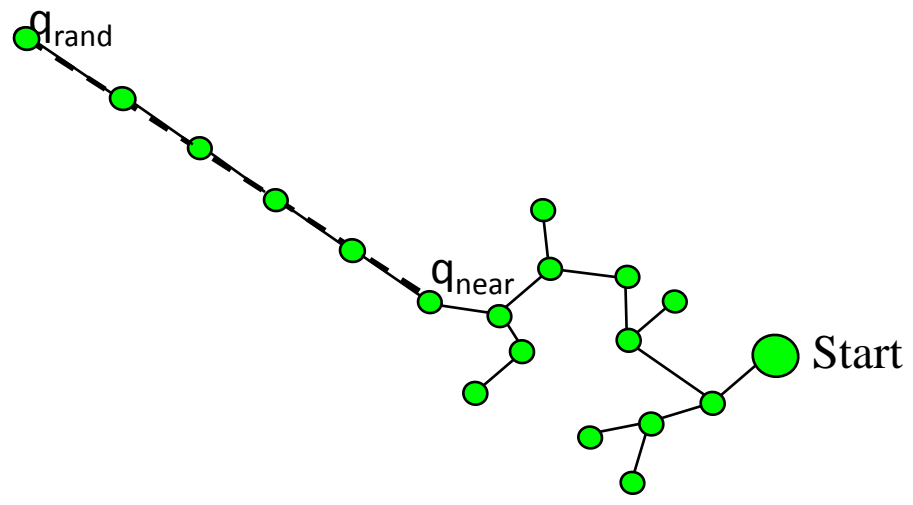
Task Space Regions

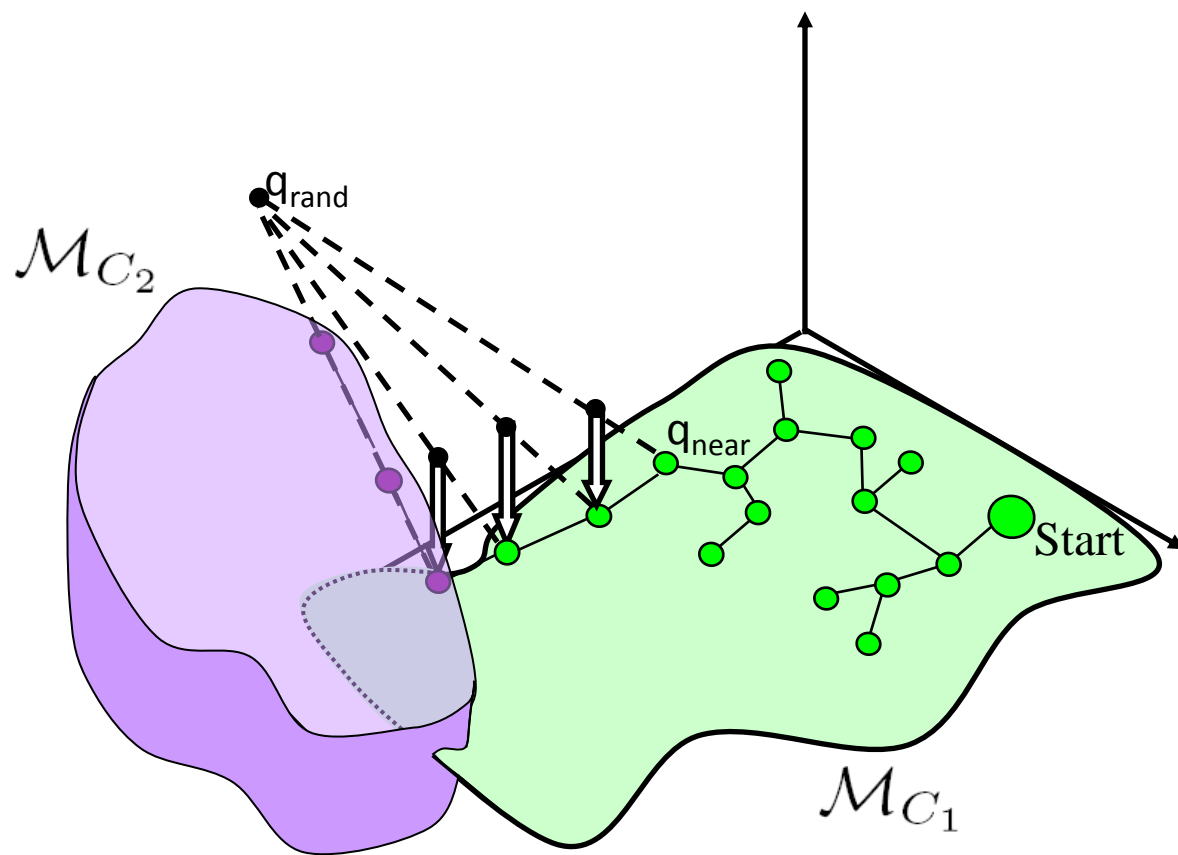


cBiRRT









Will this work?

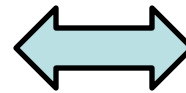
- Properties of P
- Implementing P
- Manifold Coverage
- Exploration
- Probabilistic Completeness
- **How does it work on a real robot?**

Yes [IJRR'11]

- Properties of P [ICRA'10]
- Implementing P [ICRA'09a,b]
- Manifold Coverage [ICRA'10]
- Exploration [ICRA'10]
- Probabilistic Completeness [ICRA'10]
- How does it work on a real robot?
[ICRA'09a,b IROS'09 Humanoids'09]



Physical Manipulation



Geometric Search



Parallelism

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HRI

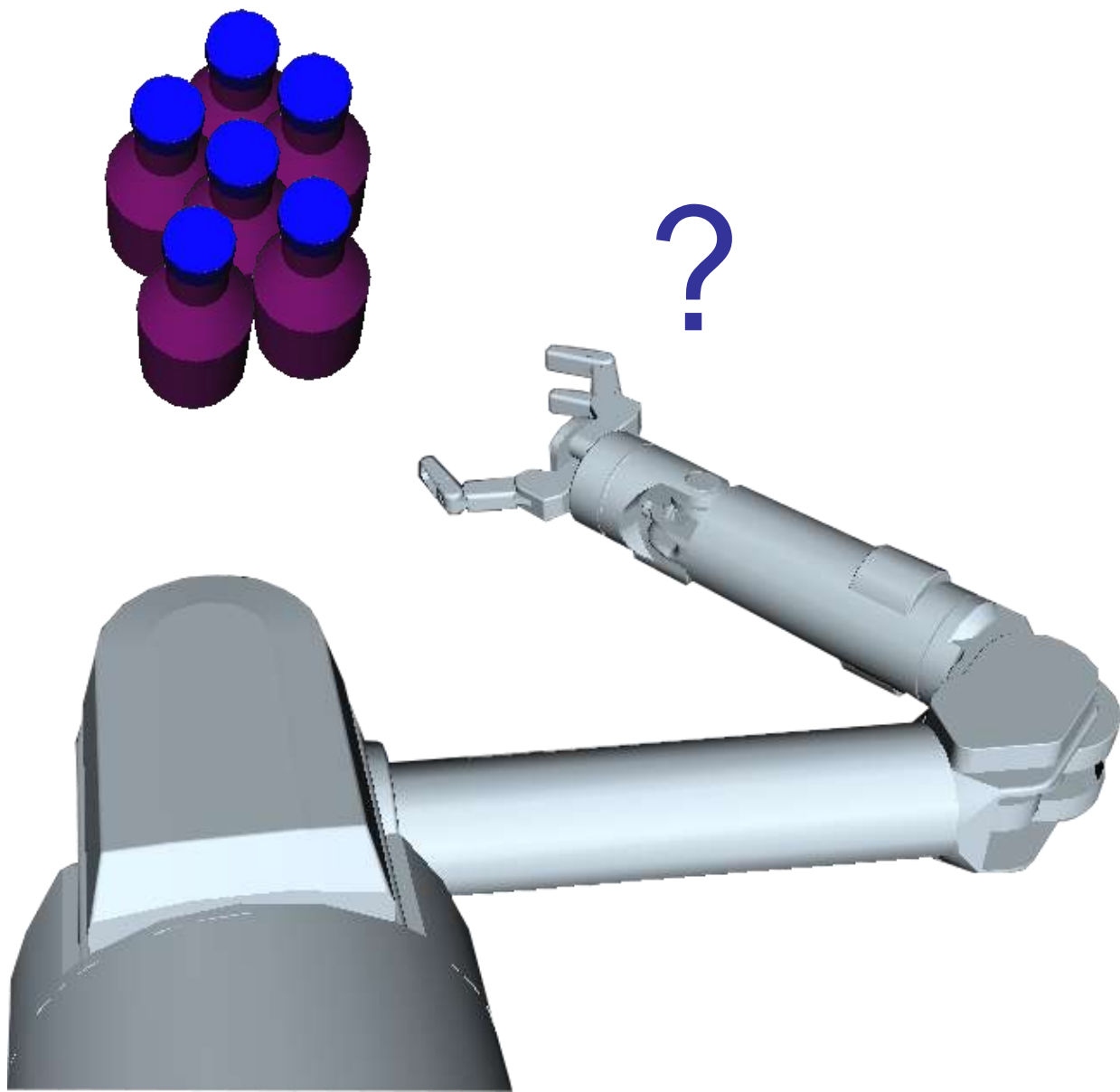
3D Modeling

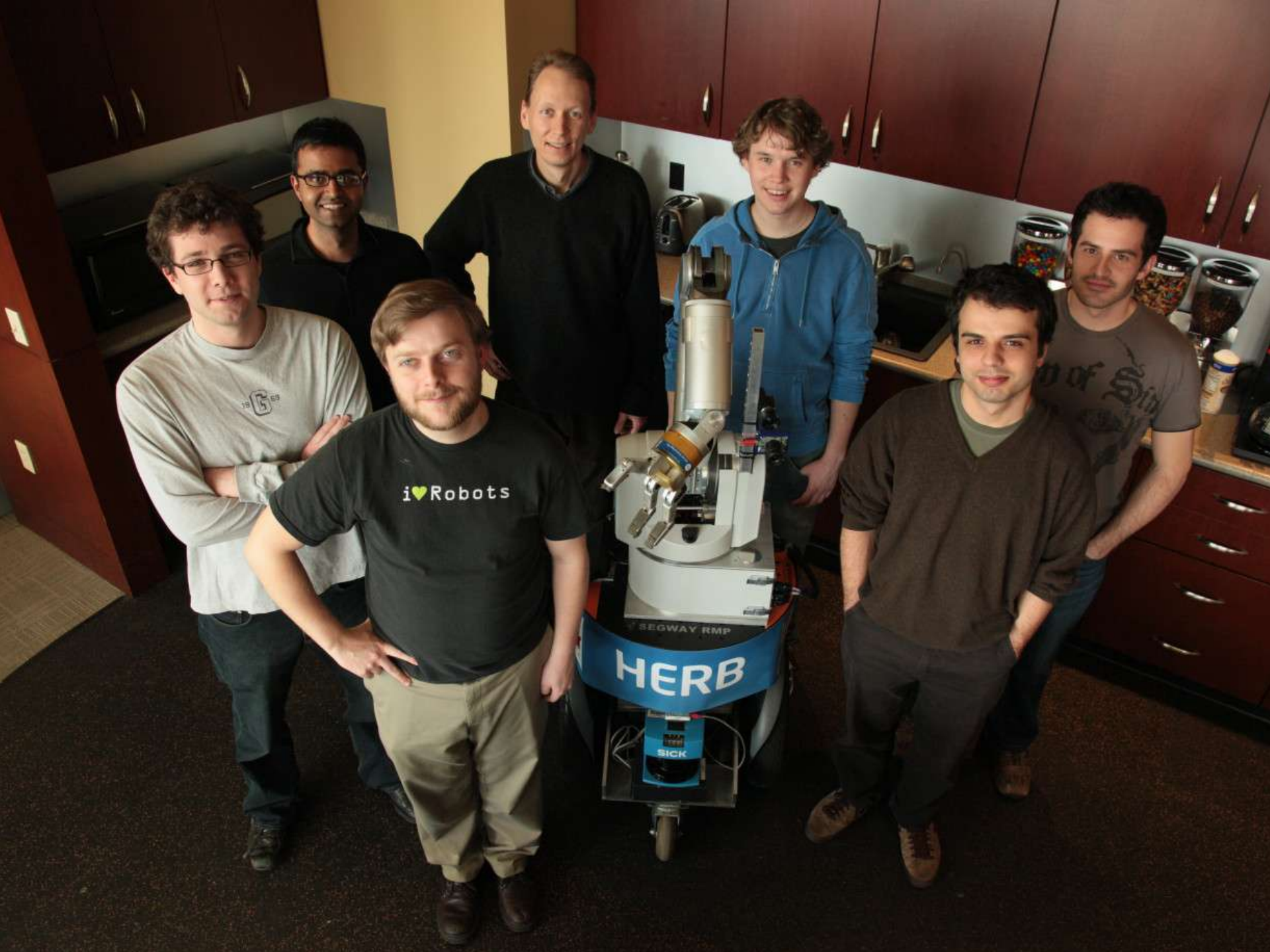
Failure : Uncertainty



Failure : Uncertainty





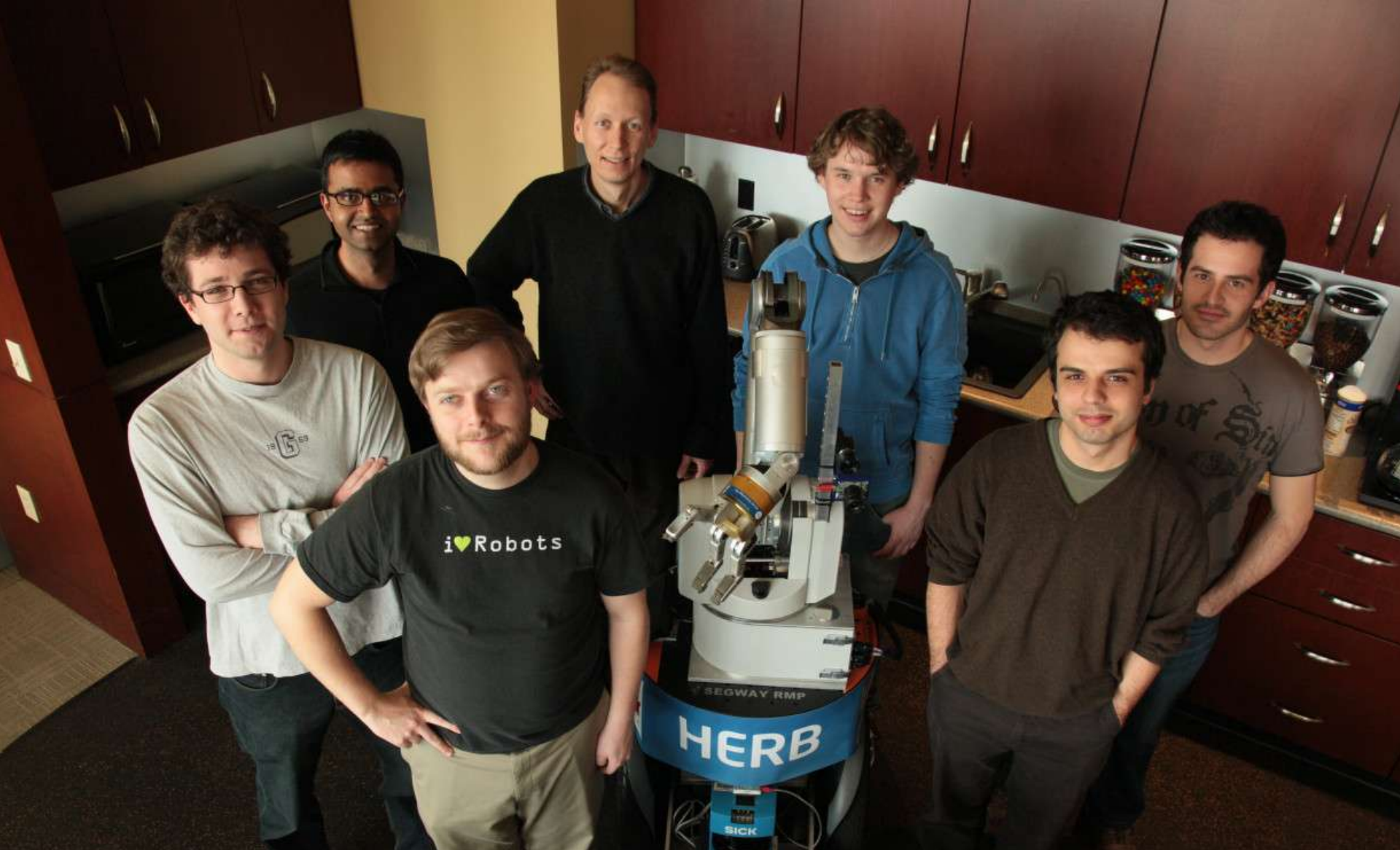


i♥Robots

HERB

SEGWAY RMP

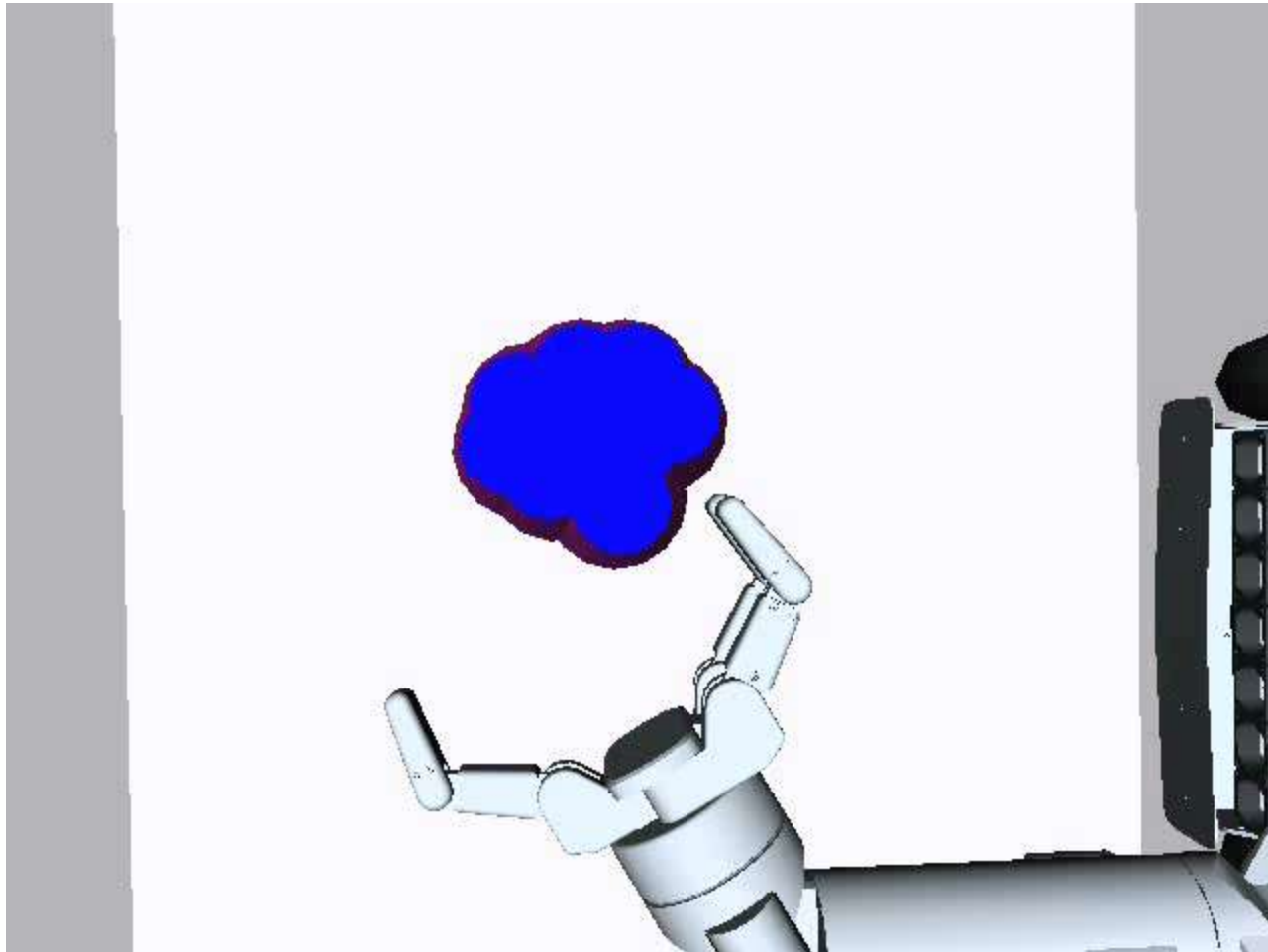
SICK



Departing Kinematics

Exploit the Mechanics of Manipulation to Funnel Uncertainty

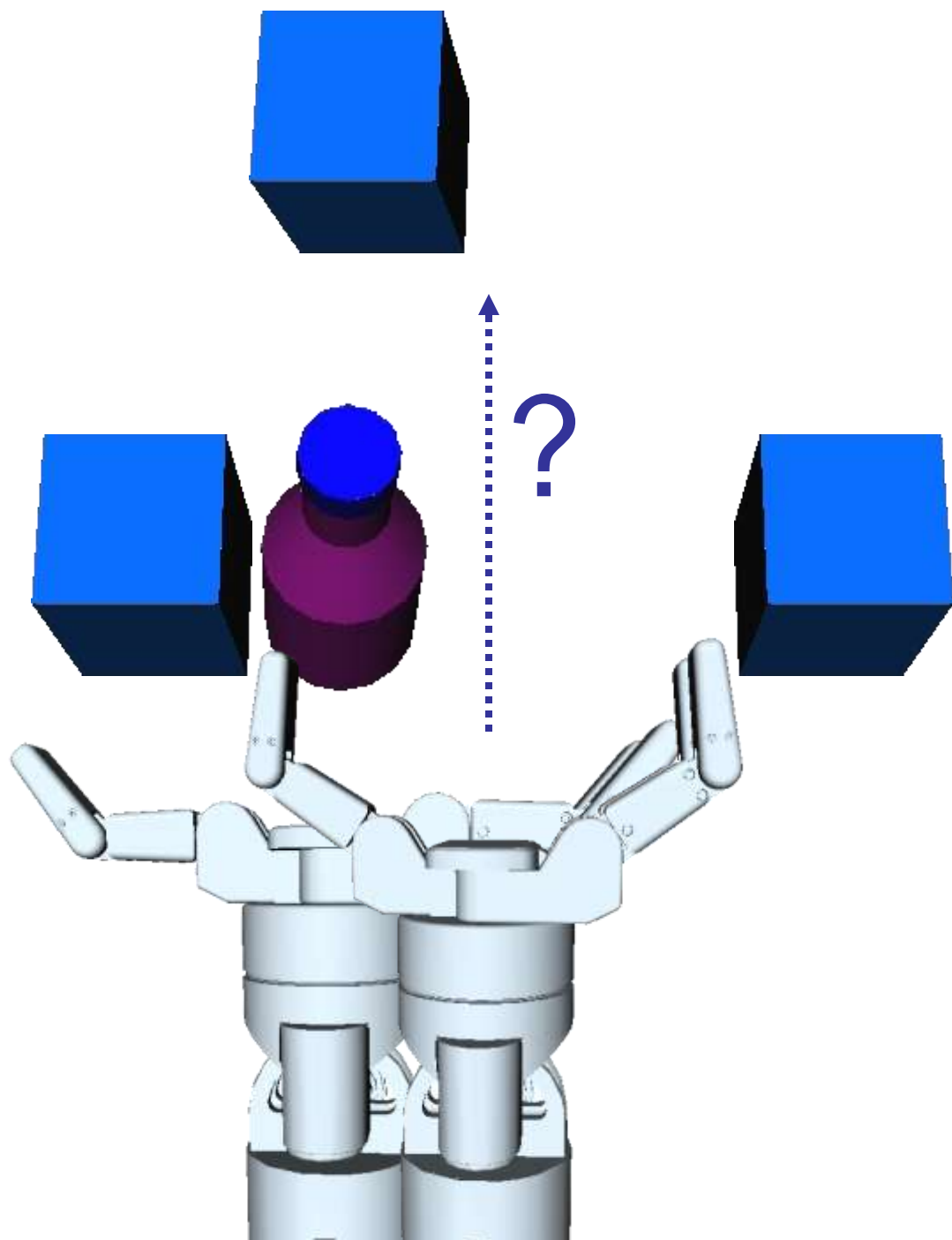
[Mason'81, Burridge et al.'99]



Why not just open
the hand wide and sweep?

Clutter







The Details of Push-Grasping

Mechanics

- What are the consequences of a push?
- How much does the robot need to know?

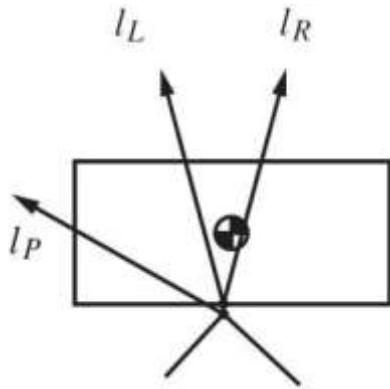
Method

- How do we address uncertainty?
- How do we plan in clutter?

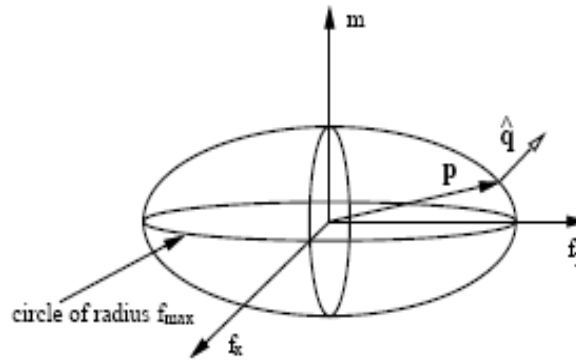
Validation

- Is our model of mechanics realistic?
- **Does push-grasping work on a real robot?**

Quasi-Static Pushing



The Voting Theorem
[Mason'81]

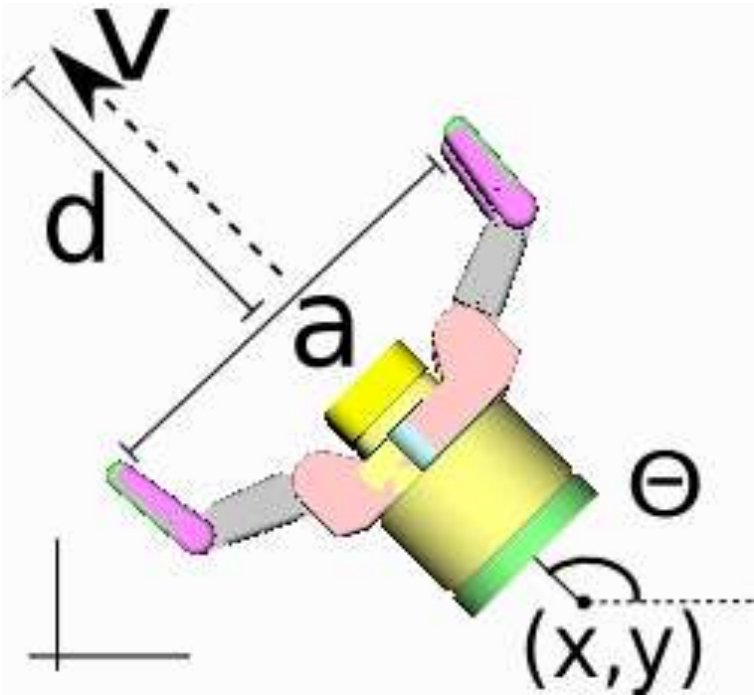


The Limit Surface
[Goyal et al.'91, Howe and Cutkosky'96]

How much should the robot know?

- Object mass? No.
- Object-surface friction? No.
- Object pressure distribution? Pick conservatively.
- Finger-object friction? Pick conservatively.

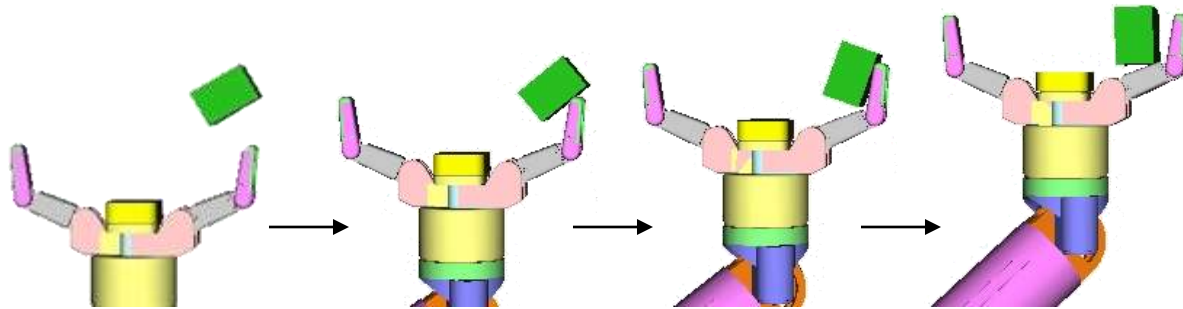
The Push-Grasp



- Hand pose: $p_h = (x, y, \mathbf{q})$
- Aperture: a
- Pushing direction: v
- Pushing distance: d

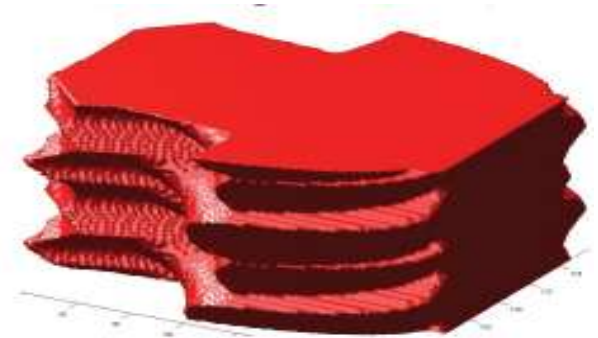
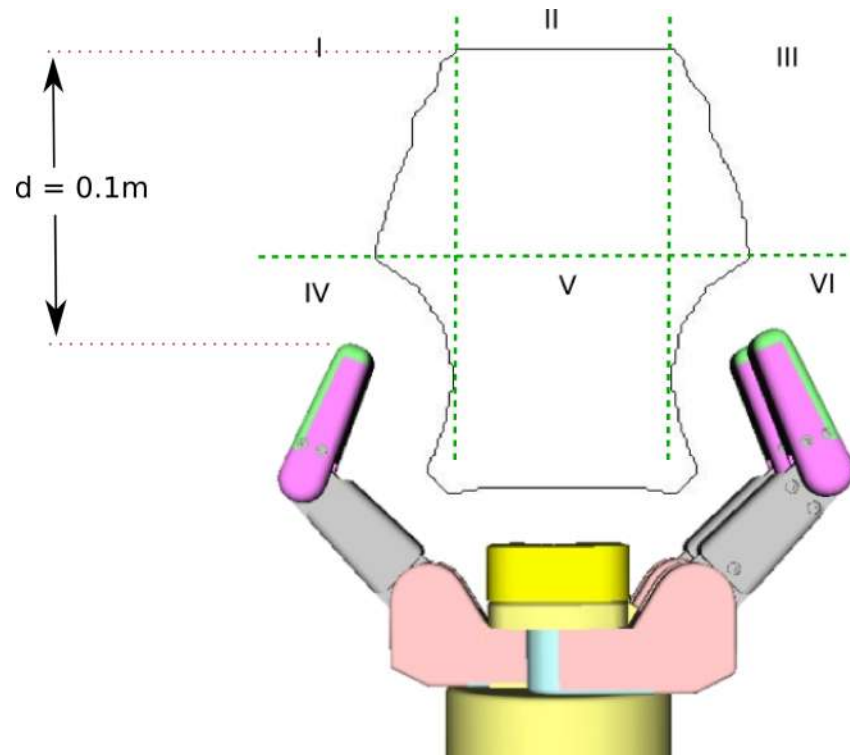
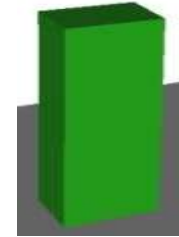
Push-Grasp: $G(p_h, a, d)$

The Capture Region

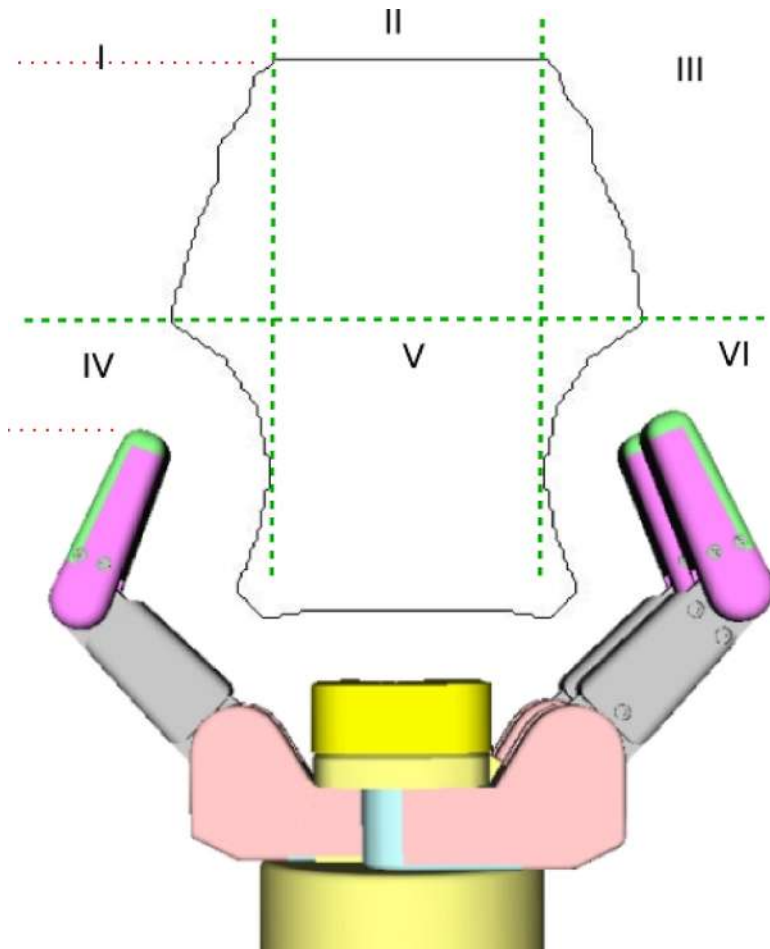


- Capture Region: $C(G, O)$
 - Set of all poses of object O that results in a successful push-grasp for G

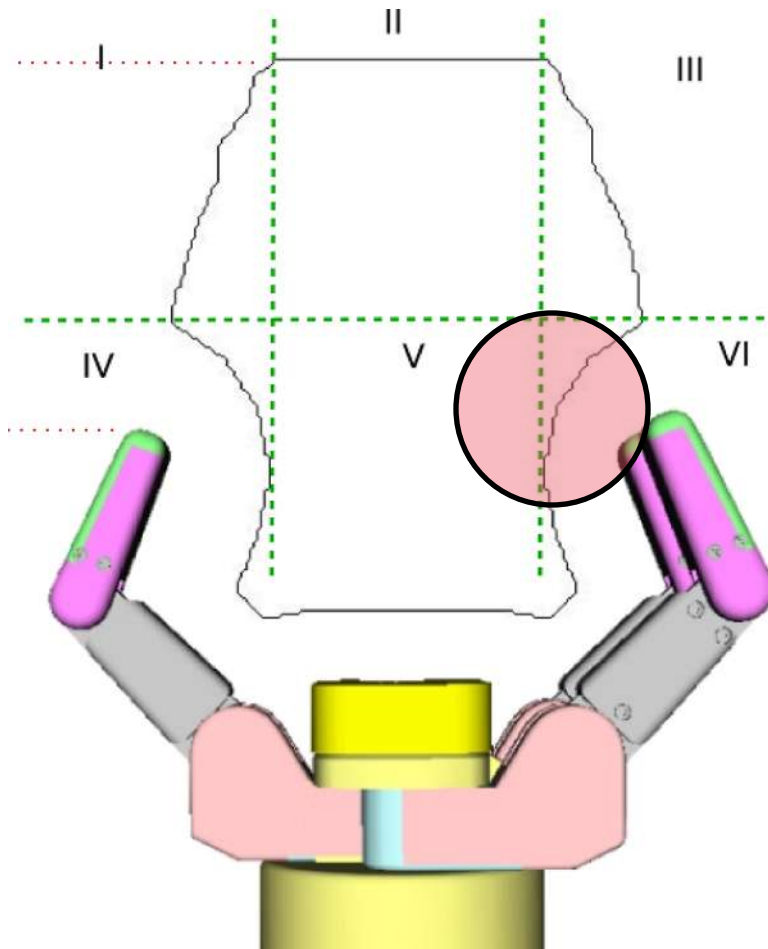
Example Capture Regions



Understanding Capture Regions

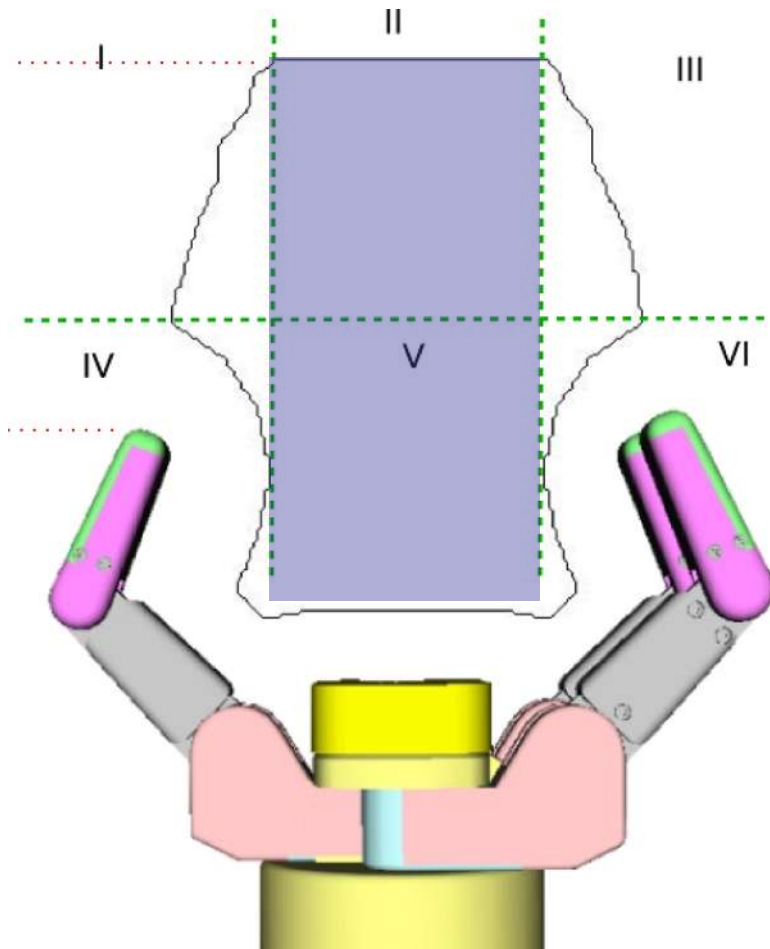


Understanding Capture Regions



IV, VI: Object contour

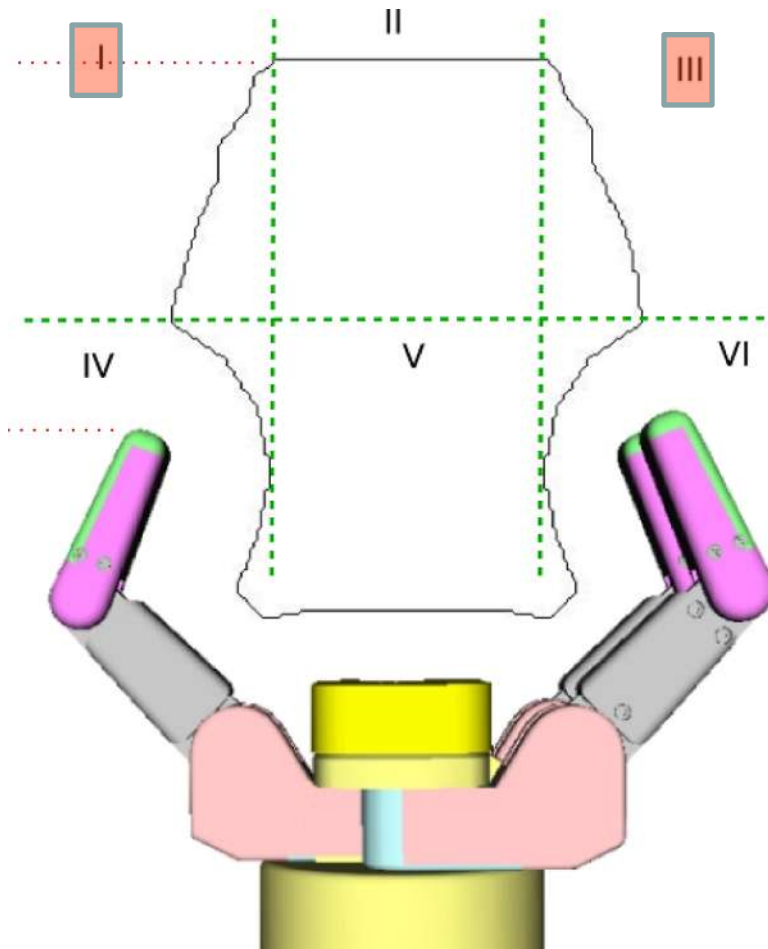
Understanding Capture Regions



IV, VI: Object contours

II, V: Caging regions

Understanding Capture Regions

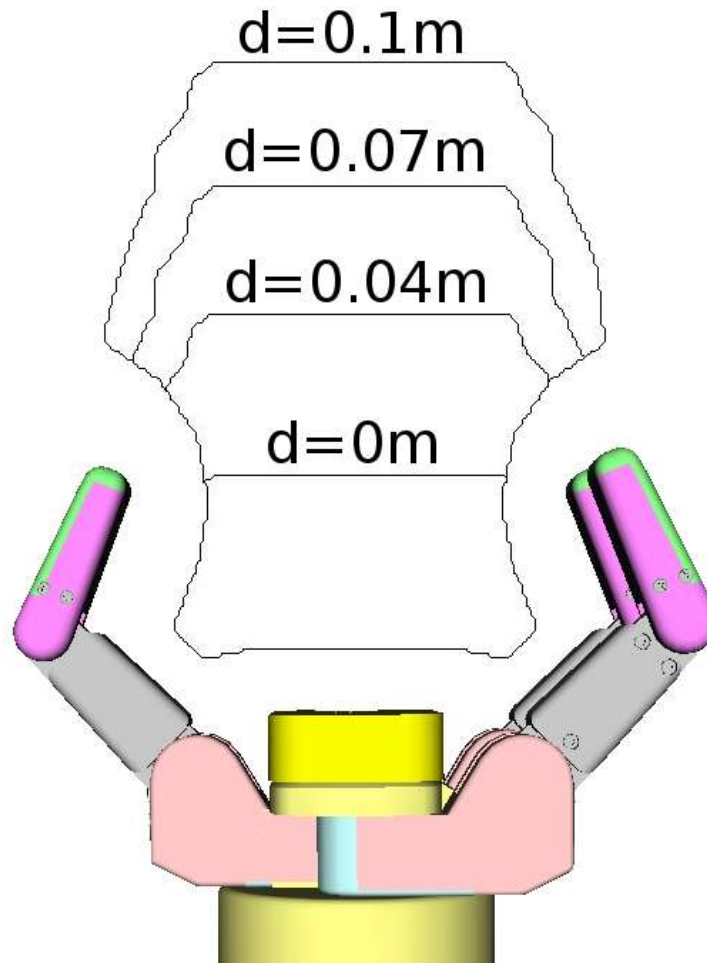


IV, VI: Object contours

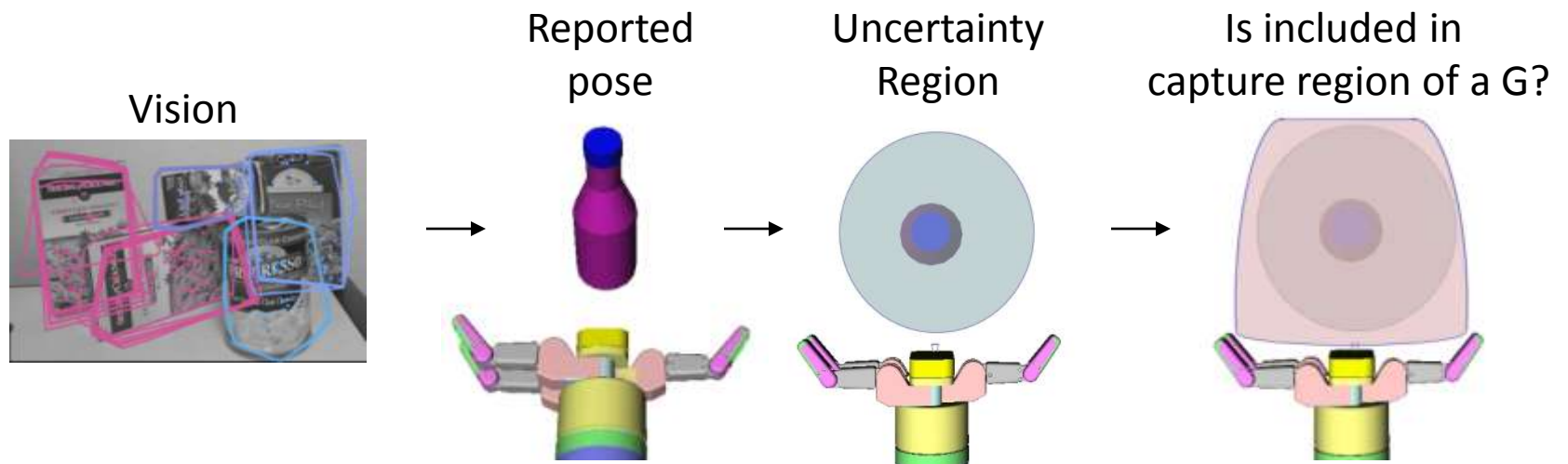
II, V: Caging regions

I, III: Pushing regions

Understanding Capture Regions



Addressing Object Pose Uncertainty



Push-grasping with clutter and uncertainty

The Details of Push-Grasping

Best Paper Award Finalist IROS 2010

Mechanics

- What are the consequences of a push?
- How much should the robot know?



Method

- How do we address uncertainty?
- How do we plan in clutter?



Validation

- Is our model of mechanics realistic?
- **Does push-grasping work on a real robot?**





US MAIL
Priority Mail
Express
Registered Mail
Signature Required
Insured
Signature Required
Signature Required

SNACKS
Let's get you and your family
ready for the school year.

HORIZON
MILK
GROWN IN THE USA

PEPSI

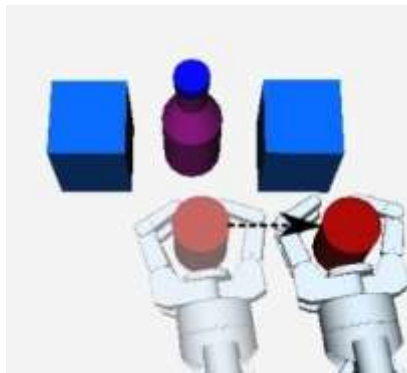
SNACKS
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FRUIT
FLAVORED
MILK

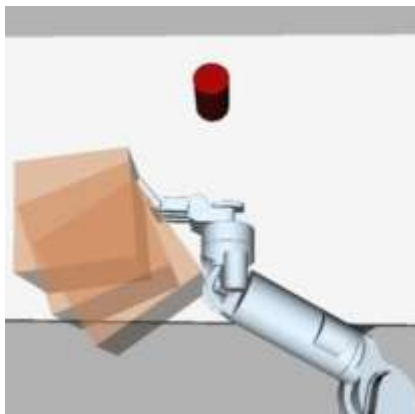


A Framework for Push-grasping in Clutter

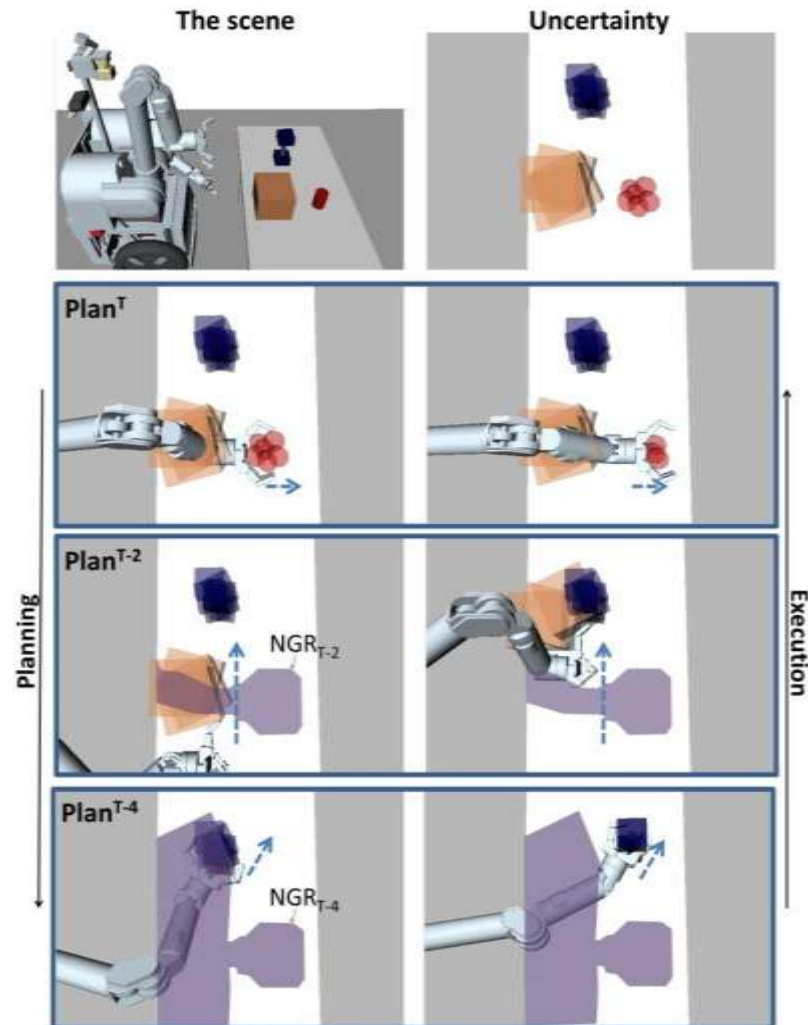
[RSS 2011 oral]

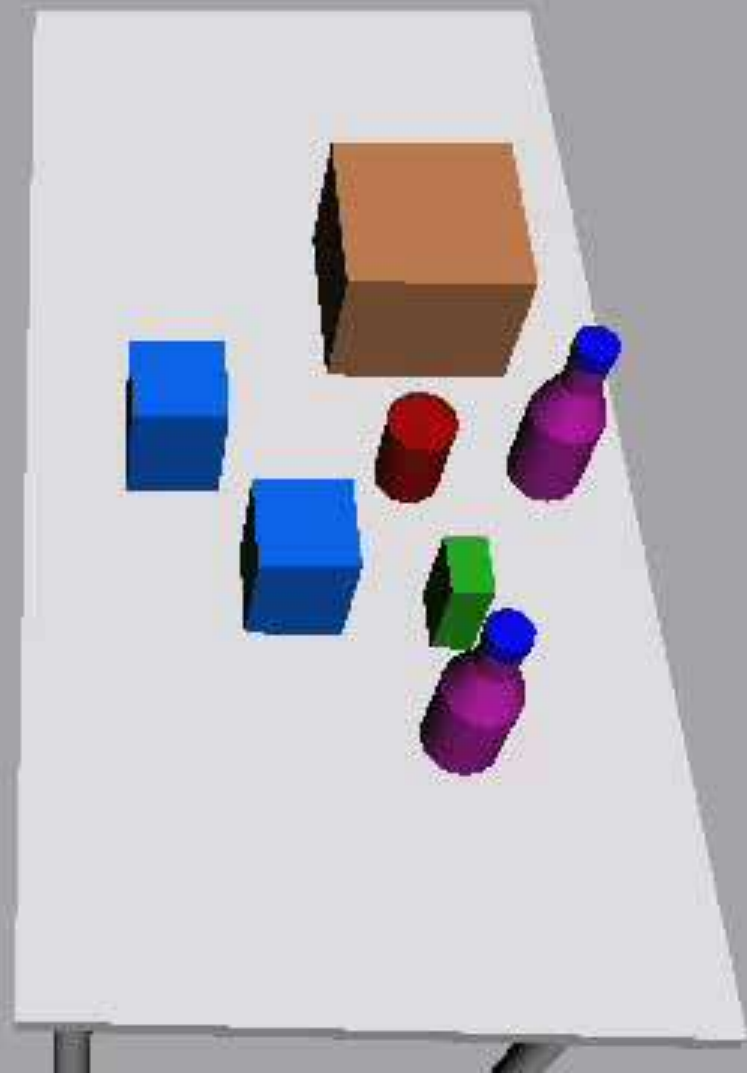
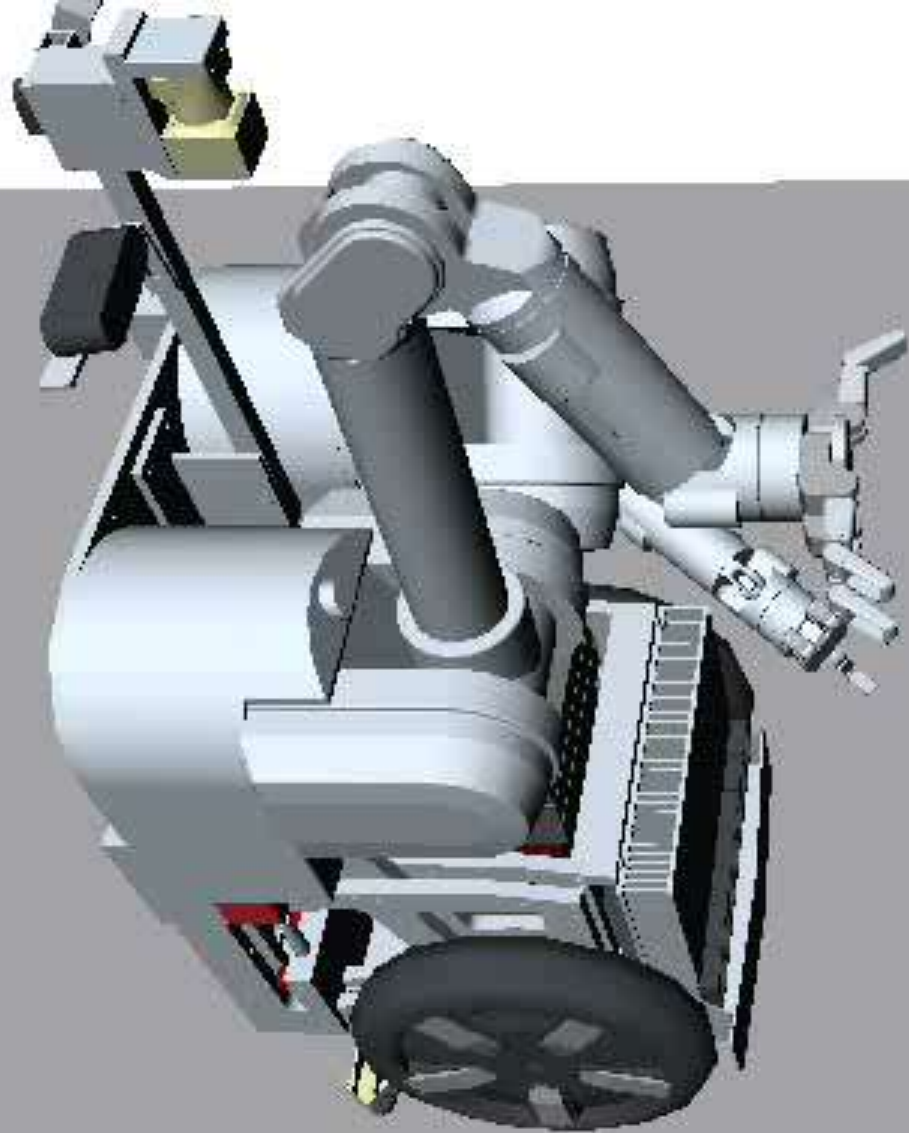


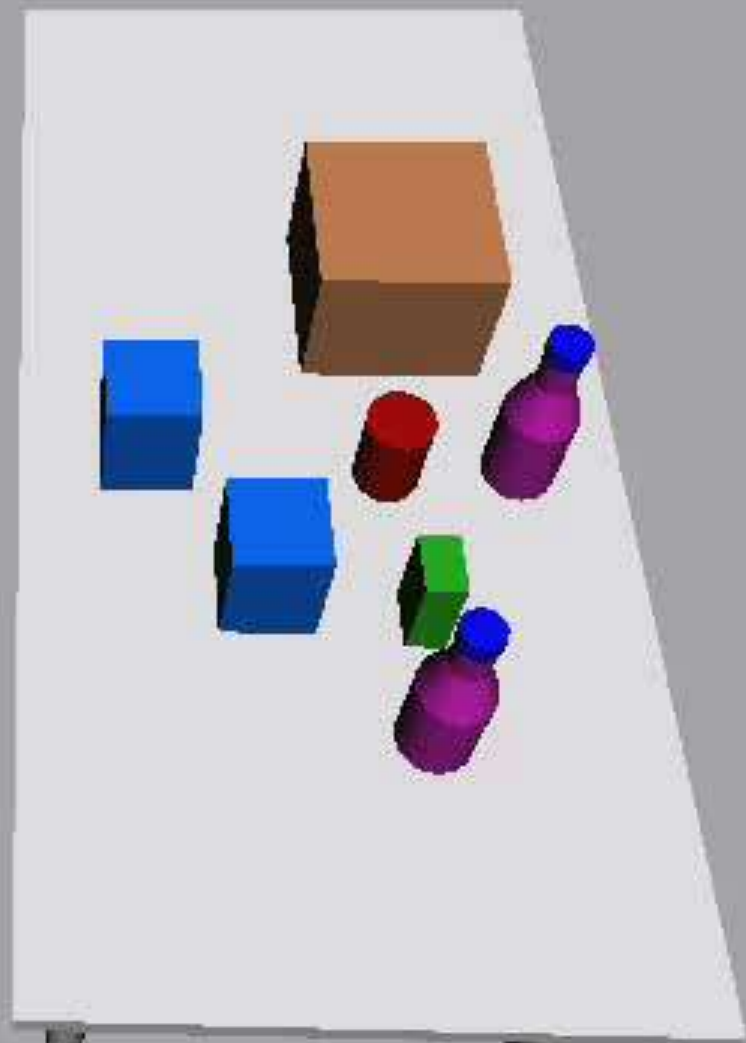
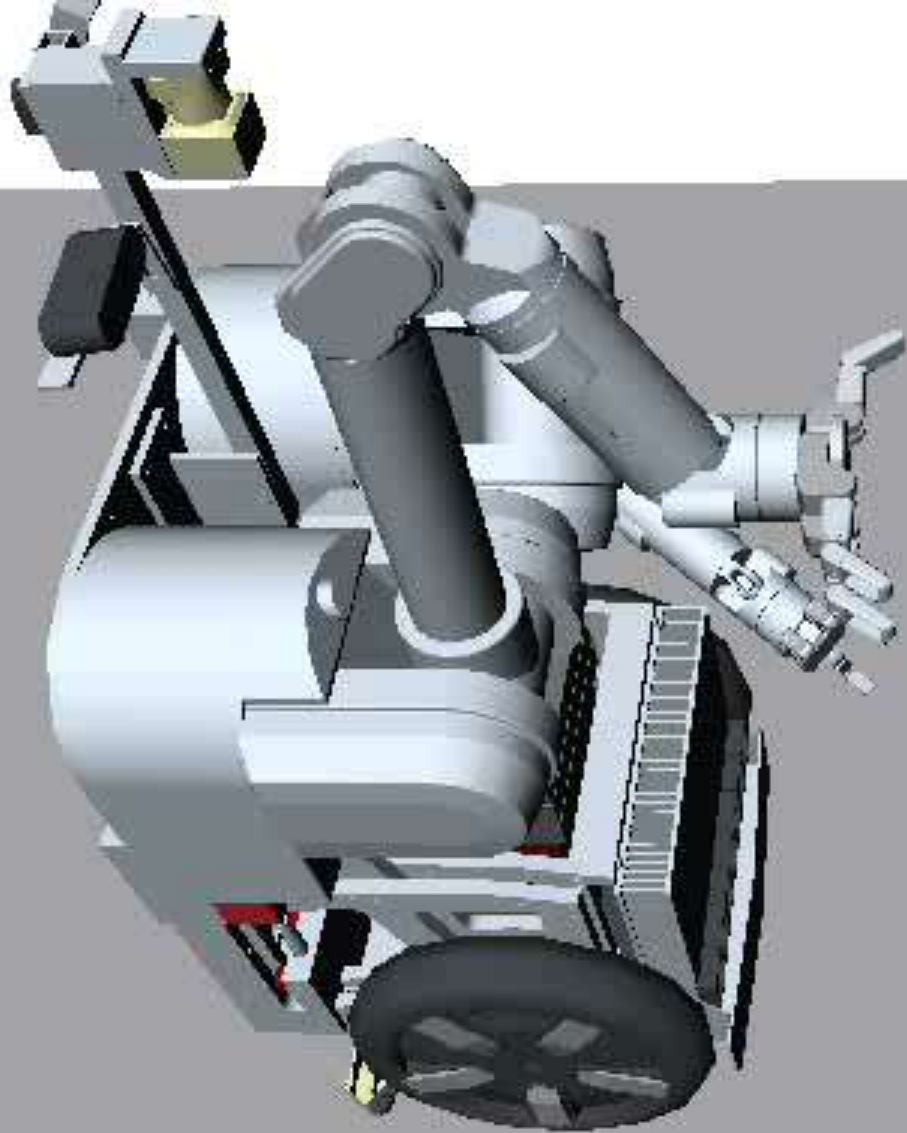
Slide-away

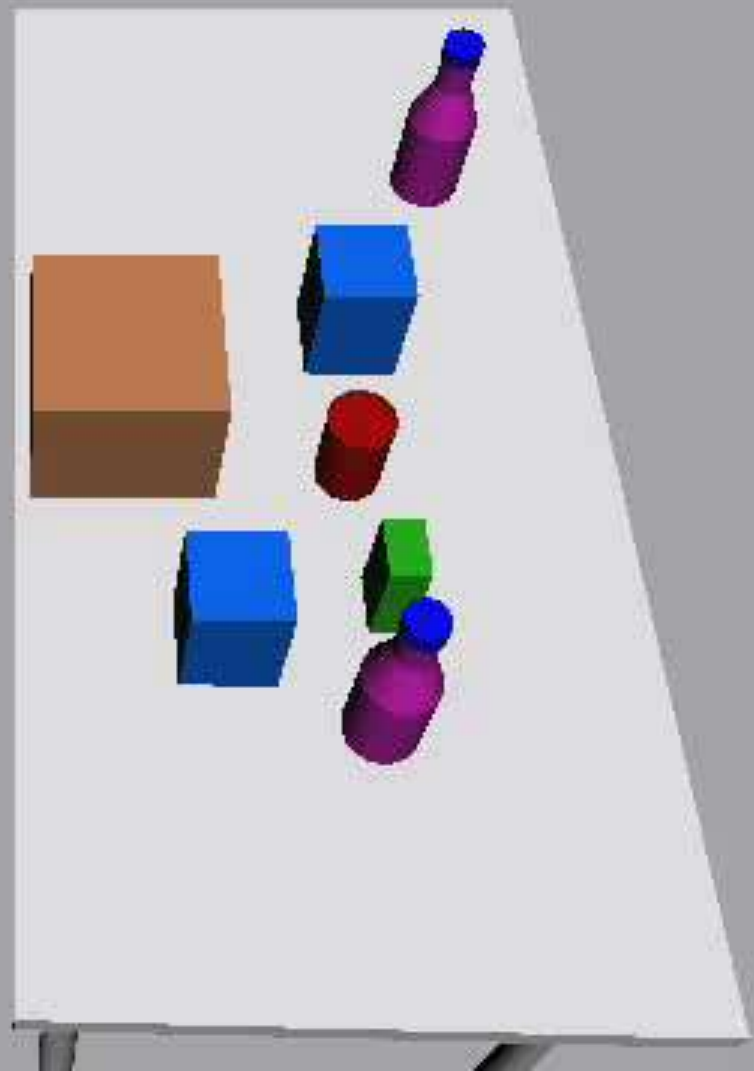
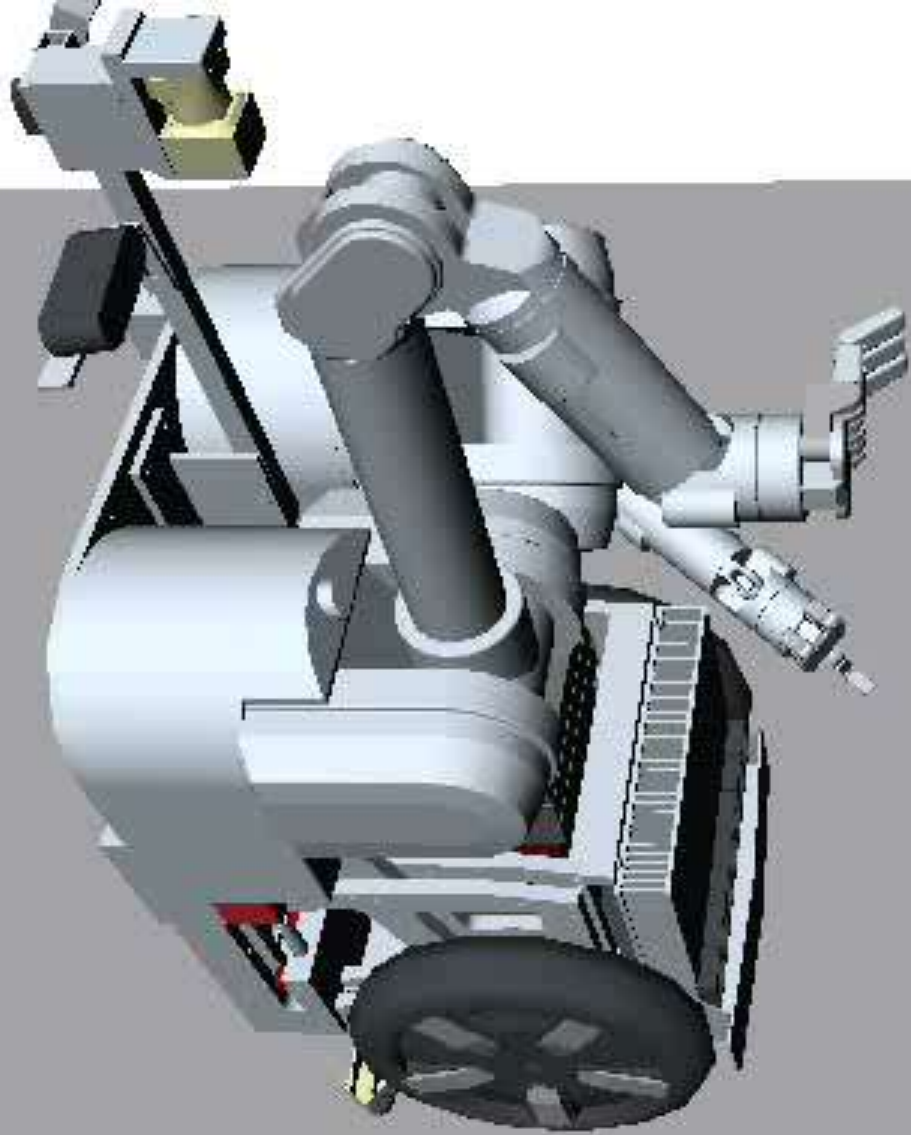


Sweep



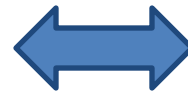








Physical Manipulation



Geometric Search



Parallelism

Navigation

Learning

Control

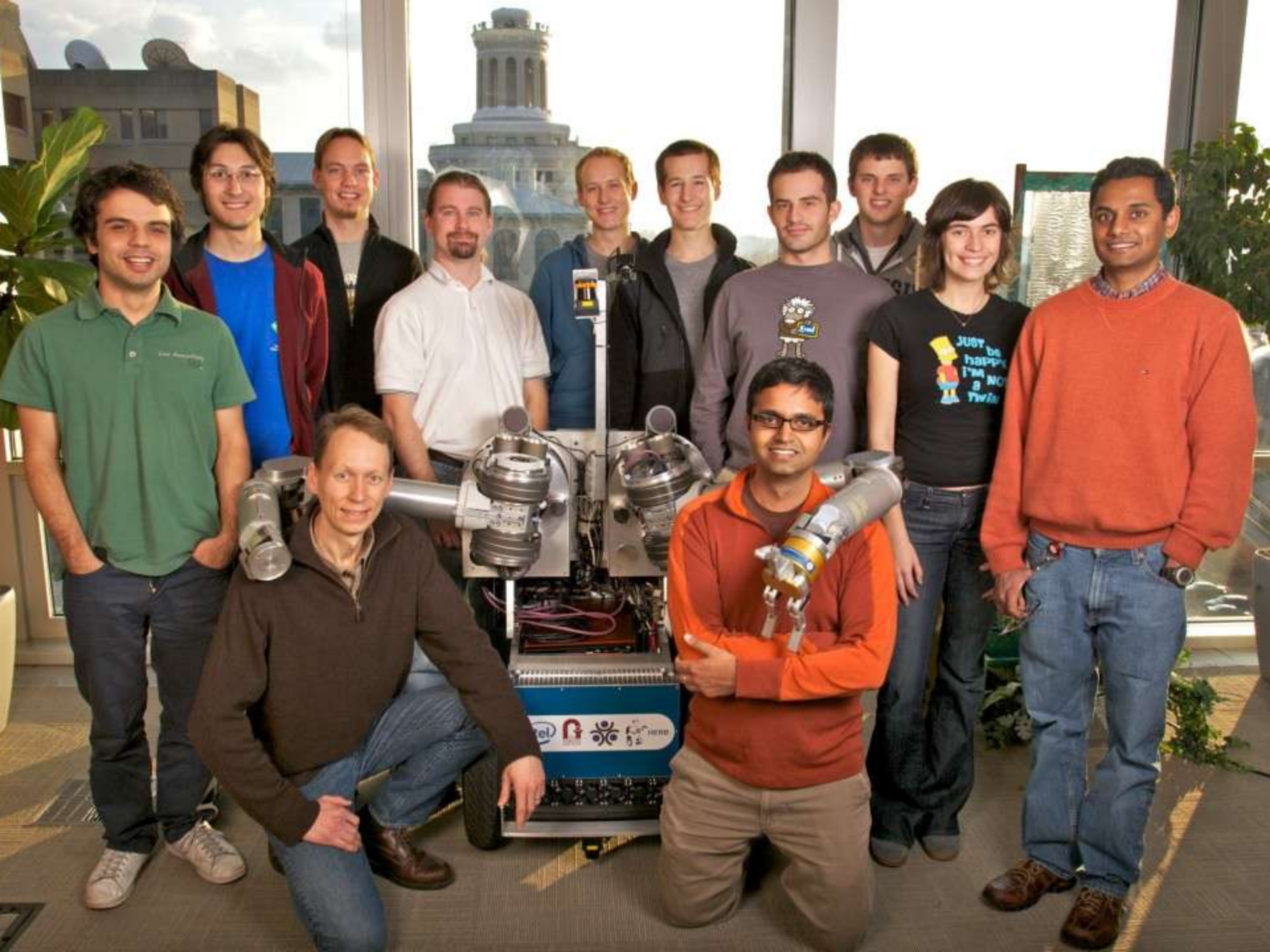
Perception

Manipulation

Systems

HRI

3D Modeling



Trajectory
Optimization

Behavior
Engine

People
Detection

Collaborative
Manipulation

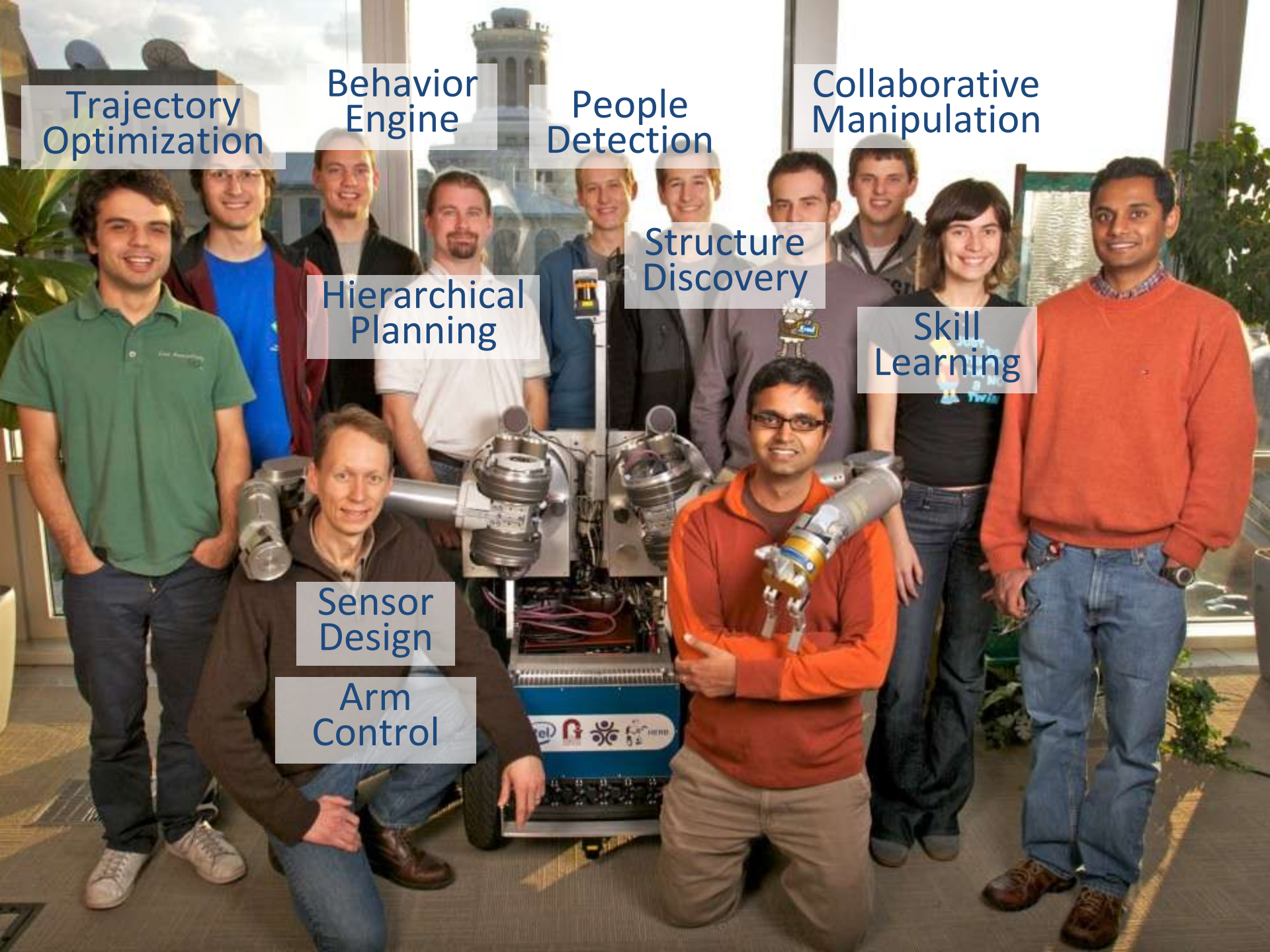
Hierarchical
Planning

Structure
Discovery

Skill
Learning

Sensor
Design

Arm
Control



- **BusinessWeek**
World's most advanced robots
- **CBS**
Robots Soon To Become Part Of Home, Work Life
- **Popular Science**
Rise of the Helpful Machines: Meet 10 of the most advanced human-assist 'bots from around the world
- **Fast Company**
Intel's Robot Butler Serves, Clears, and Does Dishes
- **Wired Magazine**
Butler Robot Can Fetch Drinks, Snacks
- **NBC Bay Area**
Robot Steals the Show at Intel Show-Off Day
- **ABC San Francisco**
Intel shows off new innovations on Research
- **NSF Science Nation**
HERB, the Robot Butler
- **CMU Link Magazine**
Robots for Life

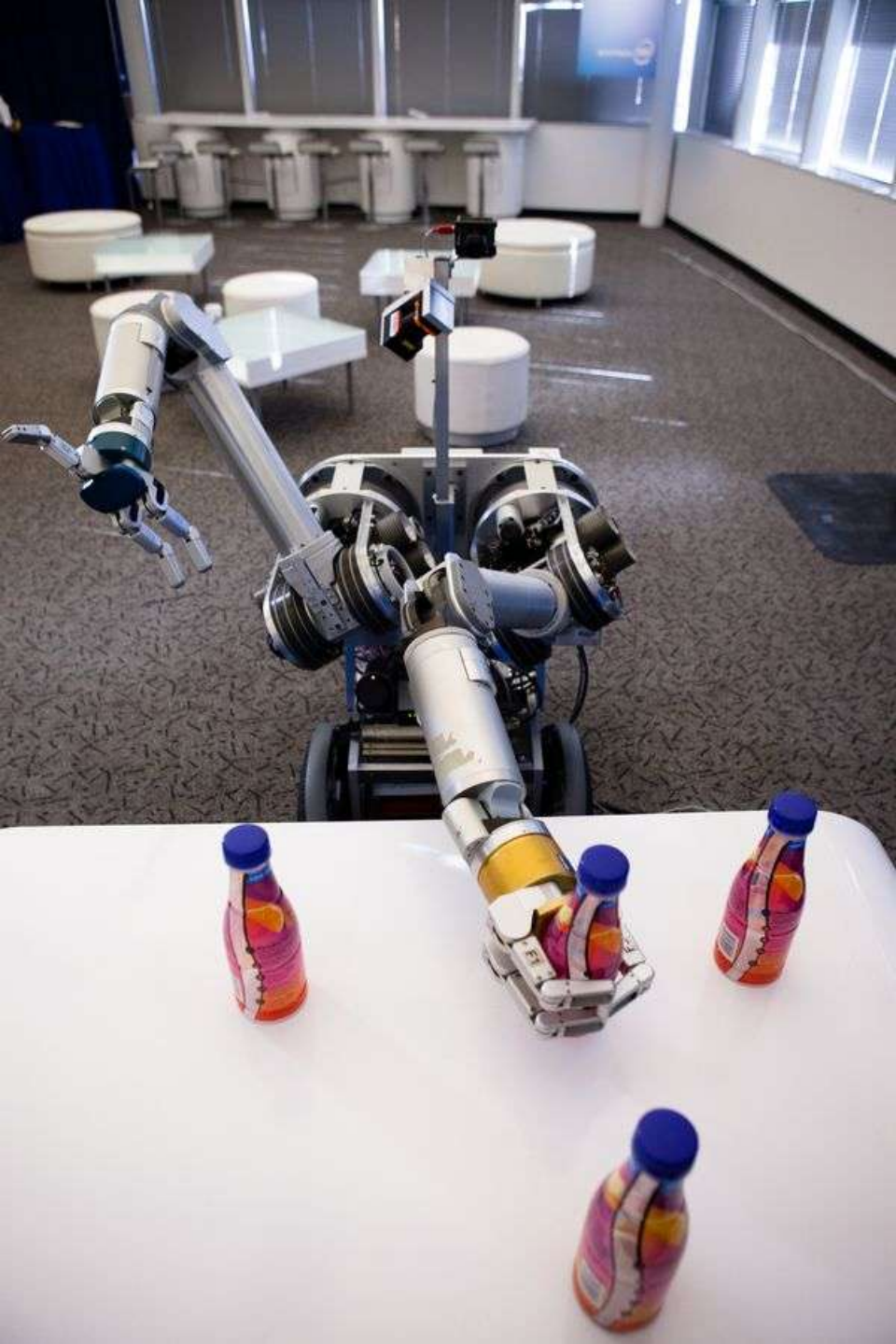




Collaborators

Peter Kaiser	Rosen Diankov
Tim Niemueller	Dave Ferguson
Peter Allen	Garratt Gallagher
Chris Atkeson	Casey Helfrich
Drew Bagnell	Bart Nabbe
Jodi Forlizzi	Nico Blodow
Martial Hebert	Maya Cakmak
Takeo Kanade	Lillian Chang
Charlie Kemp	Martin Herrmann
Sara Kiesler	Geoff Hollinger
Ross Knepper	Laura Lindzey
James Kuffner	Manuel Martinez
Min Kyung Lee	Alberto Rodriguez
Matt Mason	Martin Rufli
Nancy Pollard	Adam Rule
Ali Rahimi	Alexander Sorokin
Jim Rehg	Andrew Yeager
Thierry Simeon	Andres Vazquez
Joshua Smith	Julius Ziegler





Reconciling Geometric Planners with Physical Manipulation



Siddhartha Srinivasa

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Director
The Personal Robotics Lab