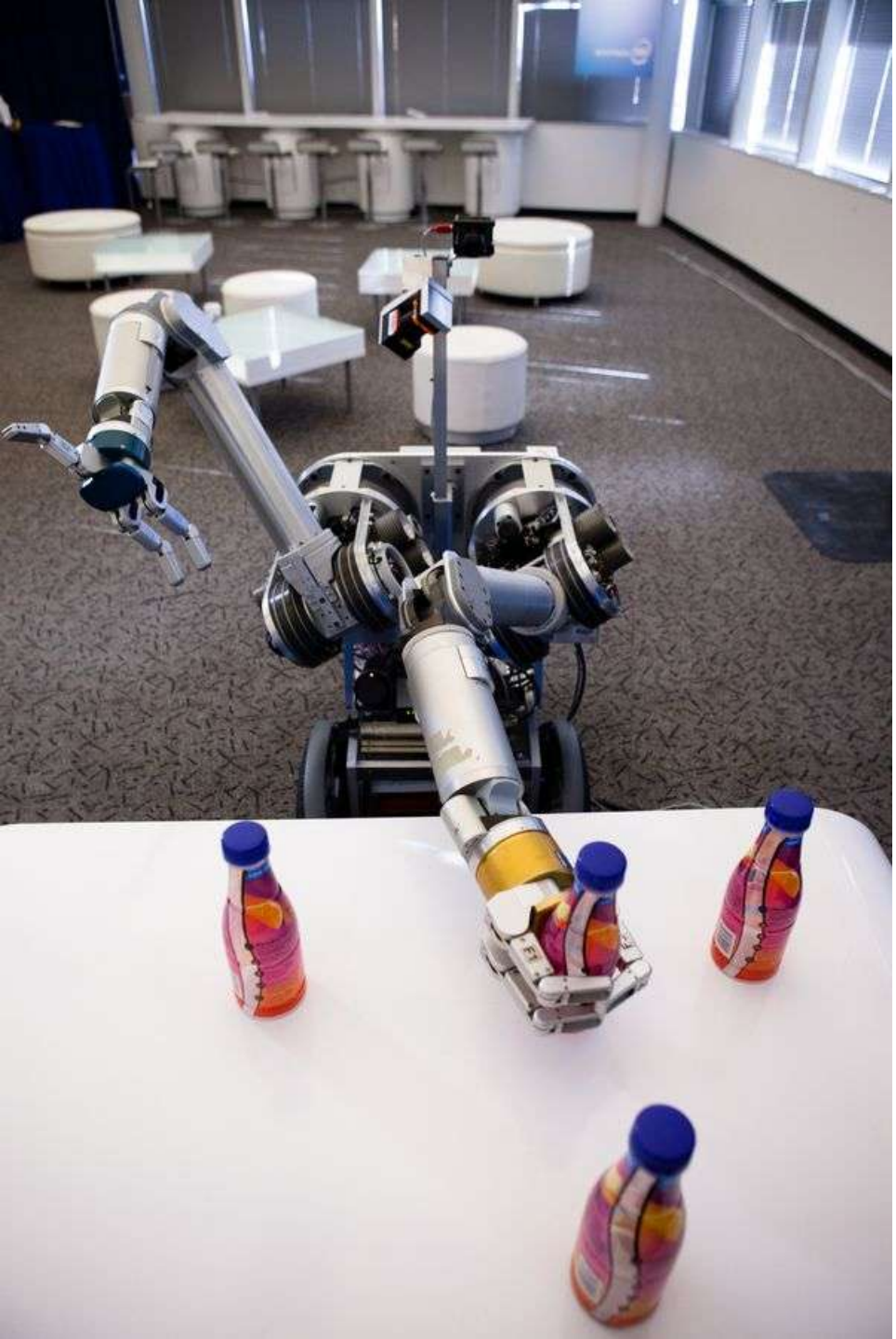
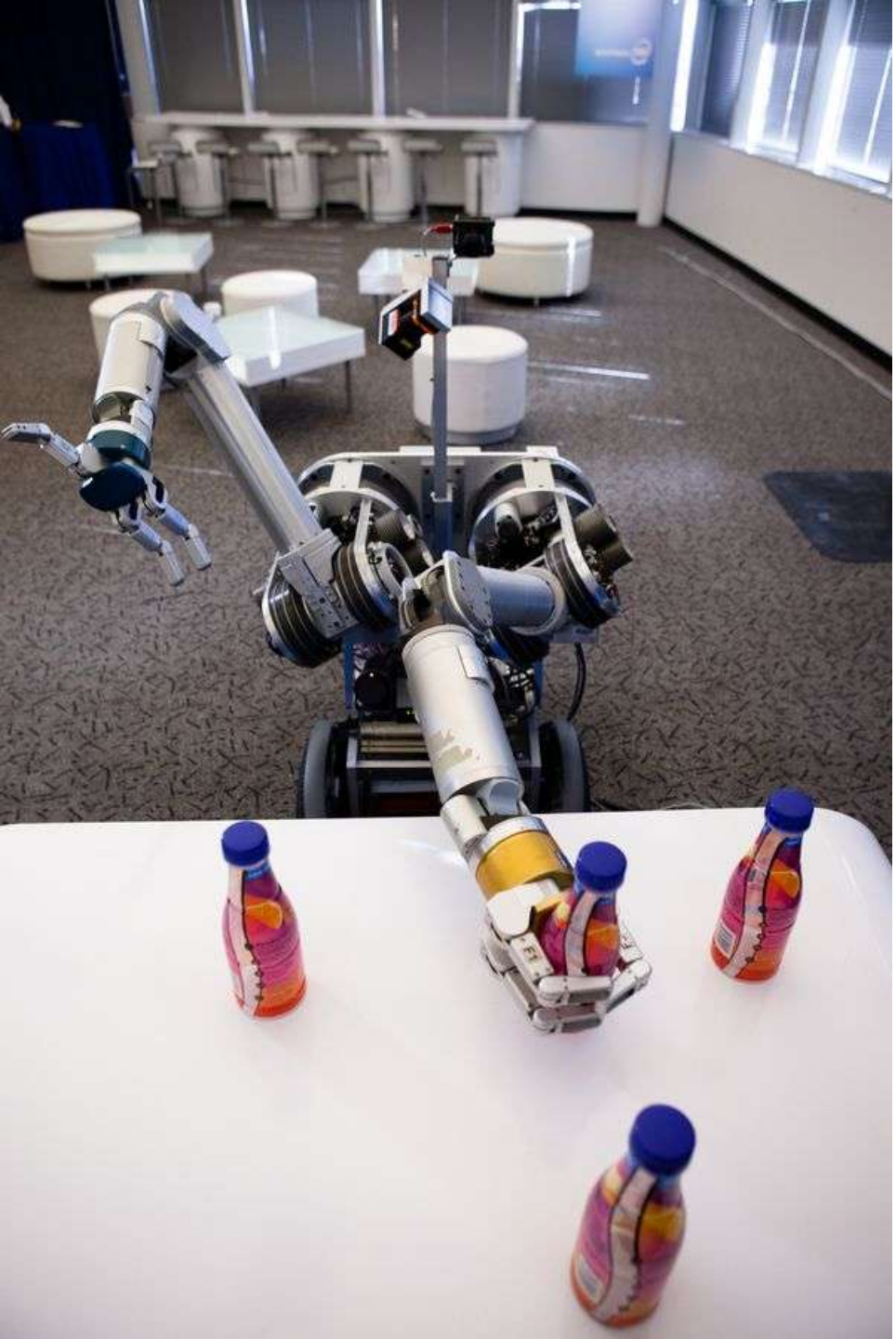


Reconciling Geometric Planners with Physical Manipulation

Siddhartha Srinivasa

Senior Research Scientist
Intel Pittsburgh

Director
The Personal Robotics Lab
The Robotics Institute, CMU



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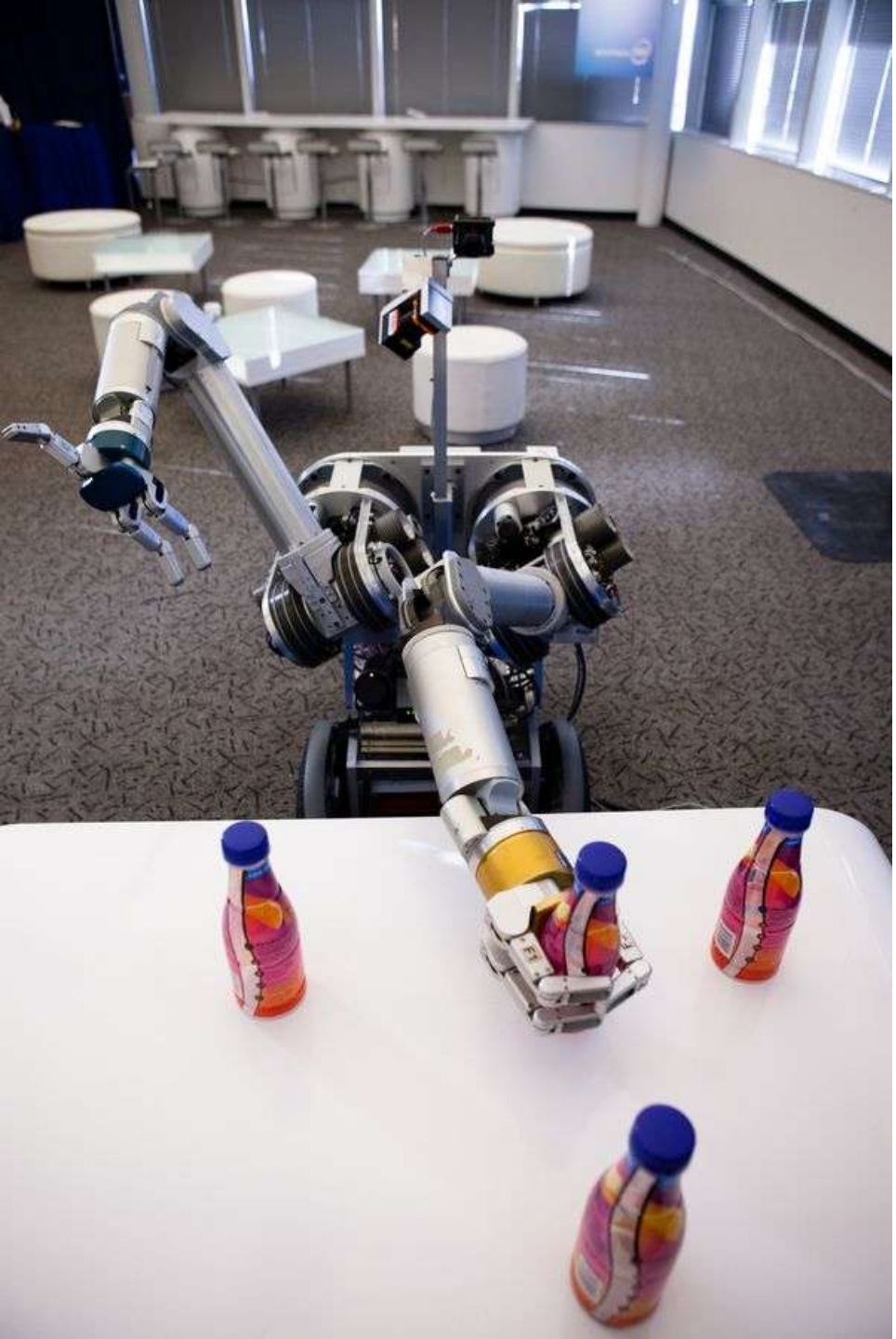

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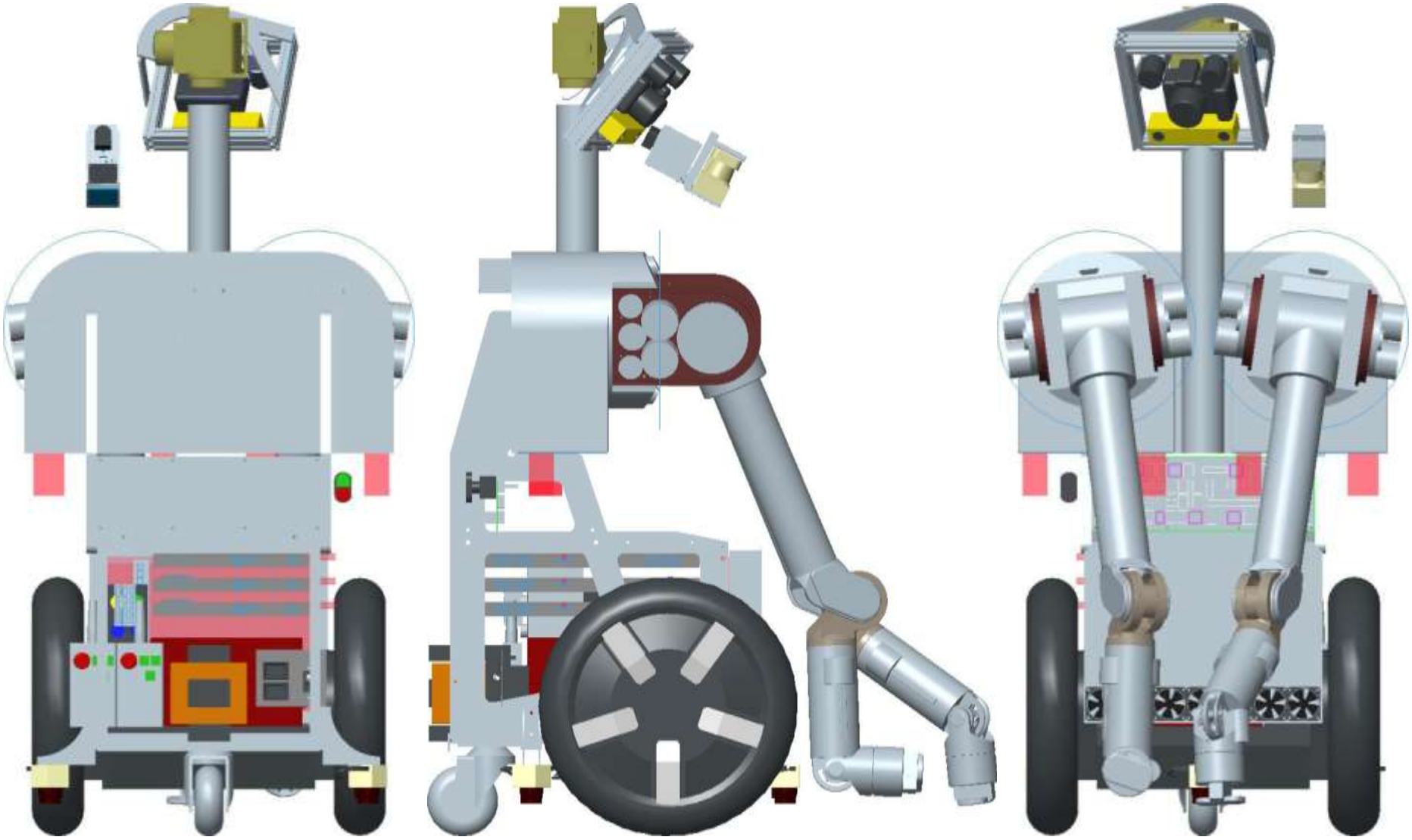
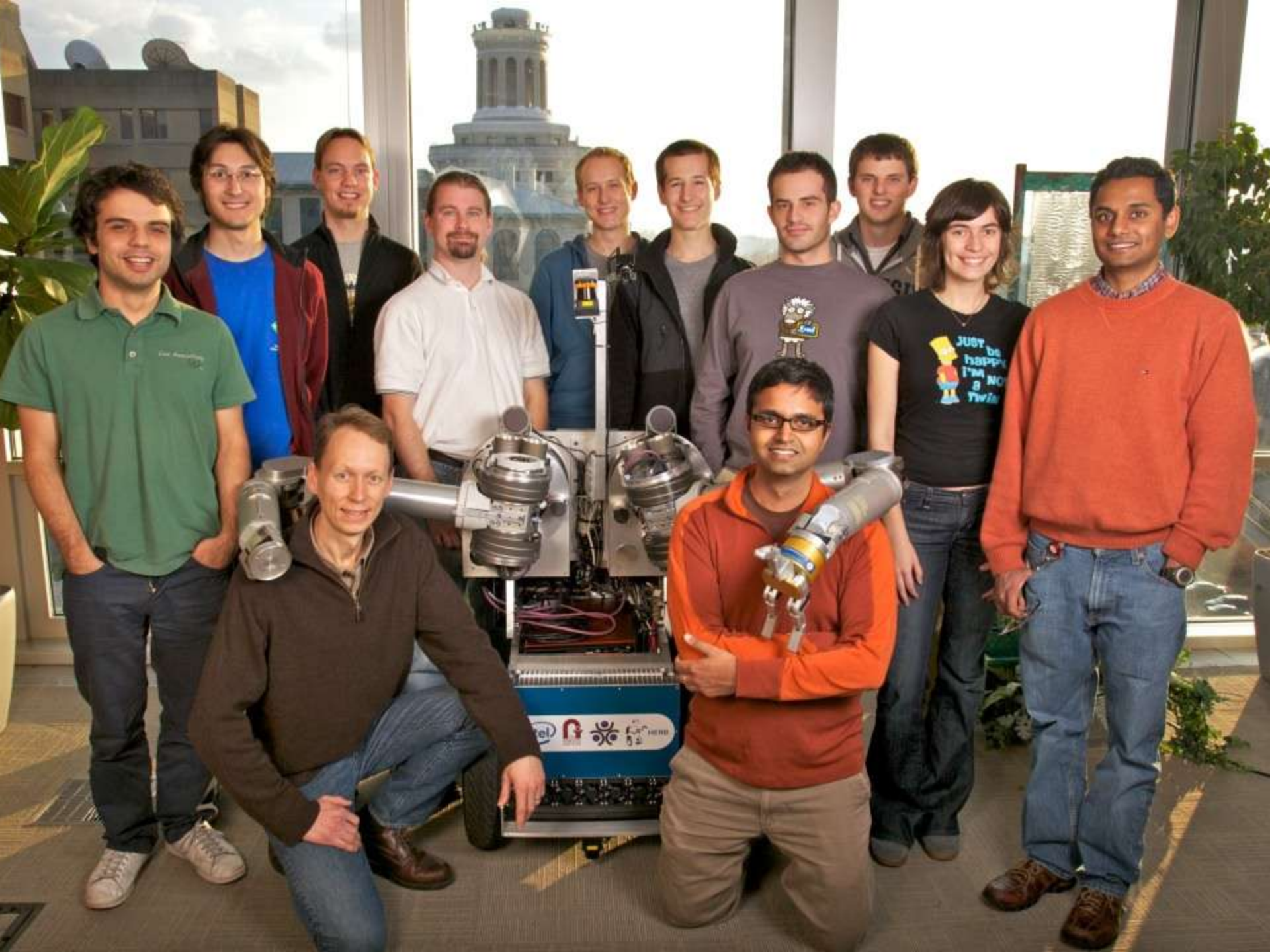



JUST be happy I'M NOT a Twin

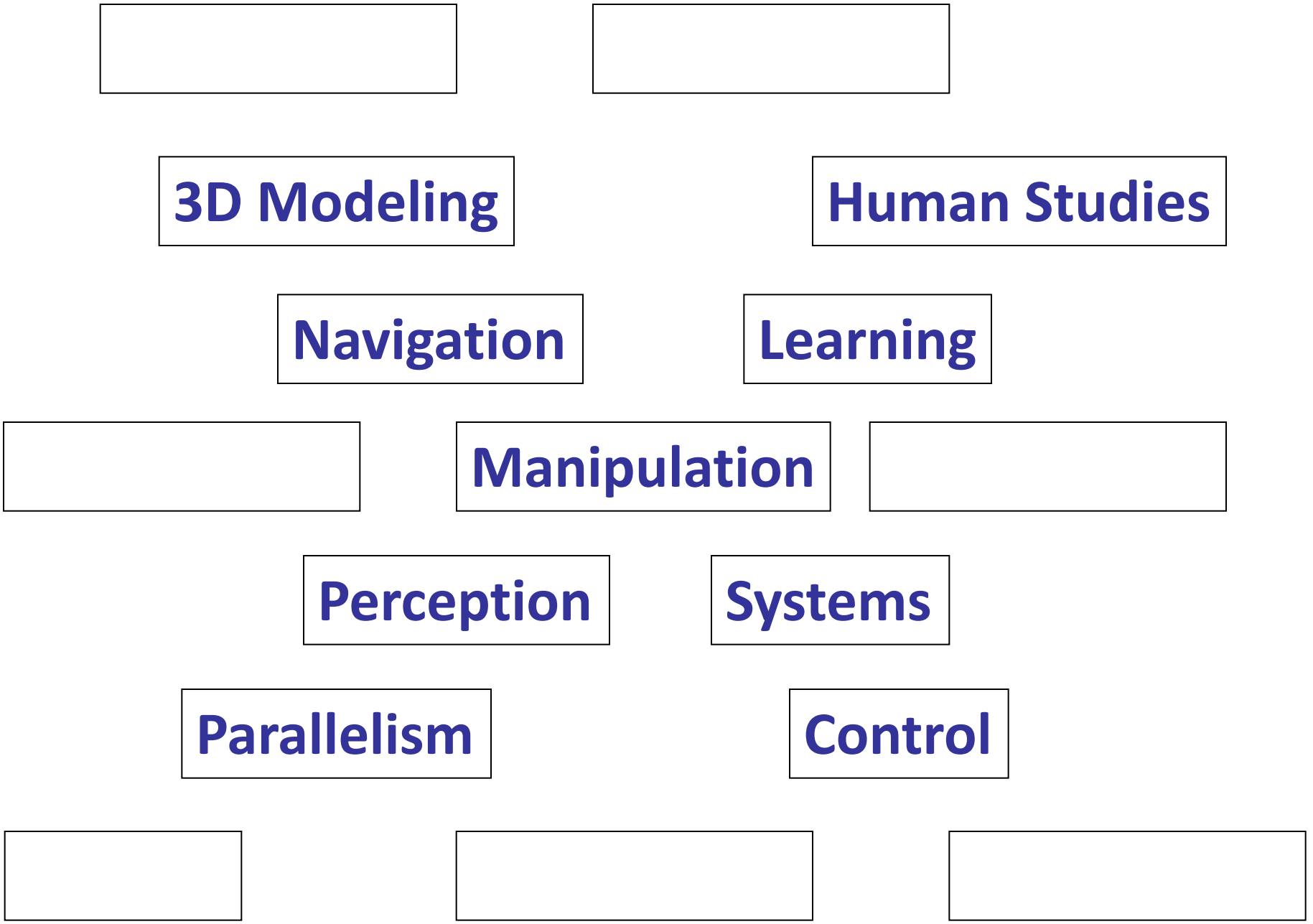
RRY KASPAROV
DEEP JUNIOR

Physical Manipulation

Geometric Search

Intel Research
Pittsburgh

Manipulation


3D Modeling
Human Studies
Navigation
Learning
Manipulation
Perception
Systems
Parallelism
Control

Physical Manipulation

Geometric Search

Parallelism

Navigation

Learning

Control

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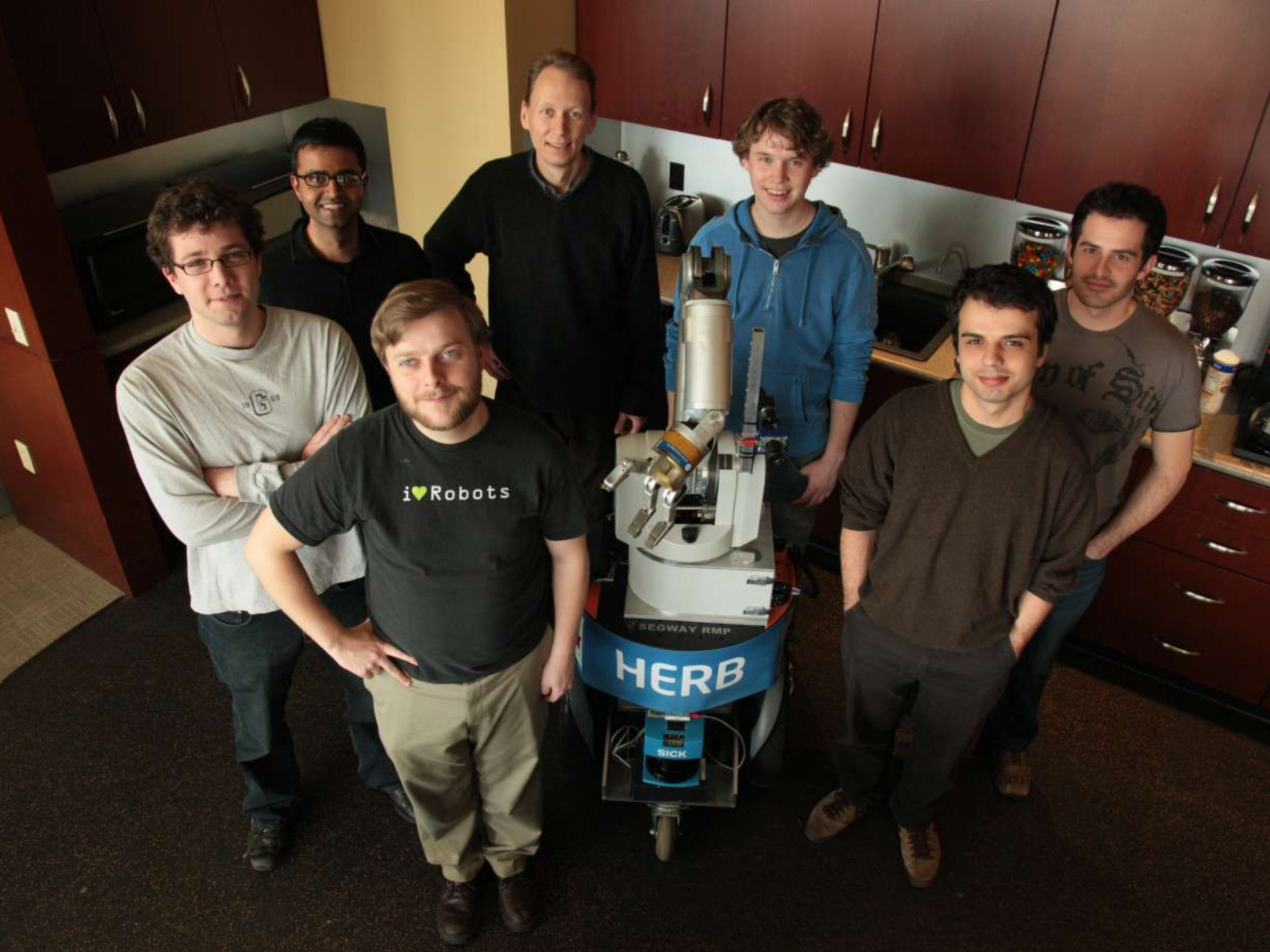
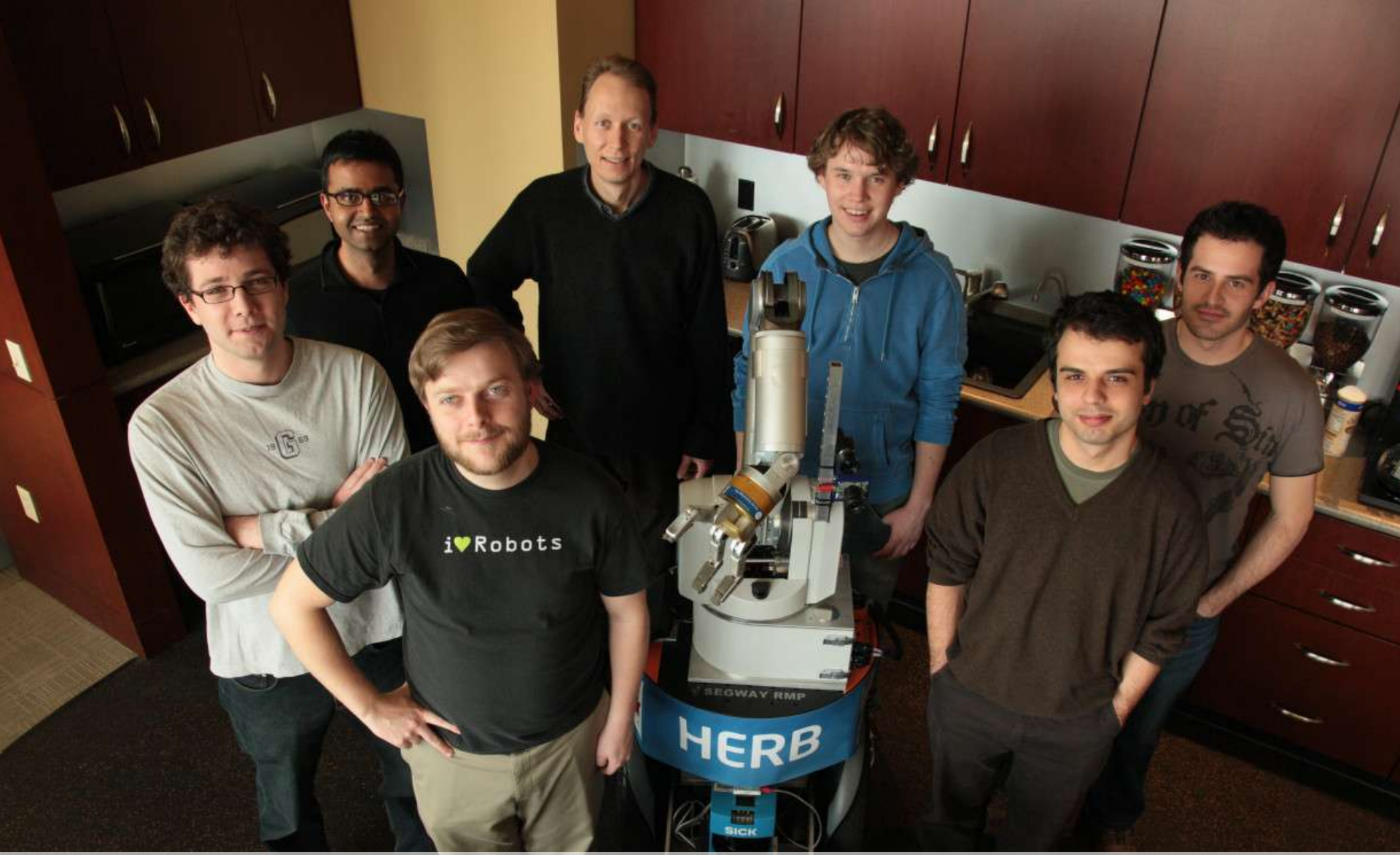

i♥Robots
SEGWAY RMP
HERB
SICK



Manipulation Planning

x3

Physical Manipulation

Geometric Search

Parallelism

Navigation

Learning

Control

Perception

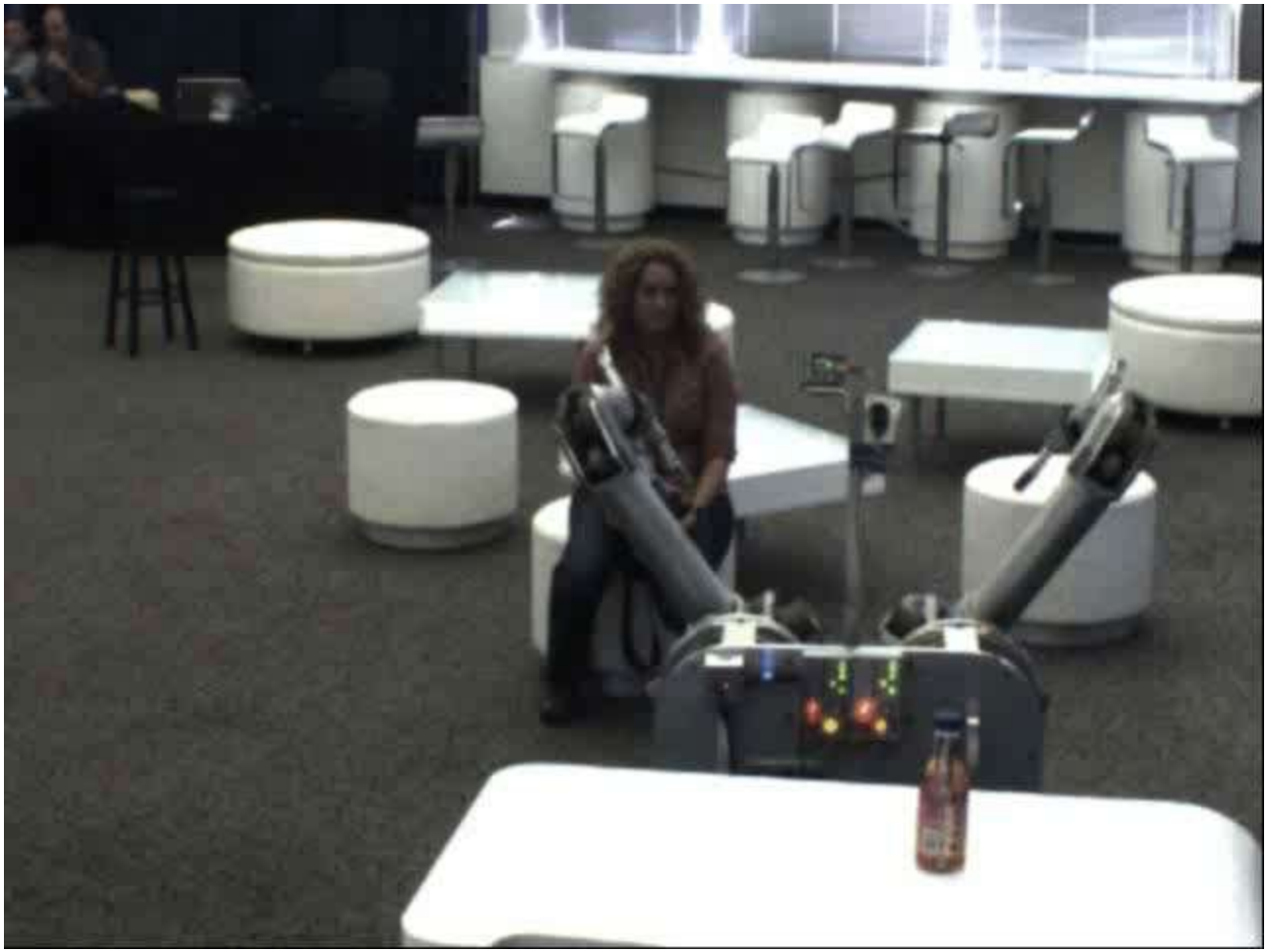
Manipulation

Systems

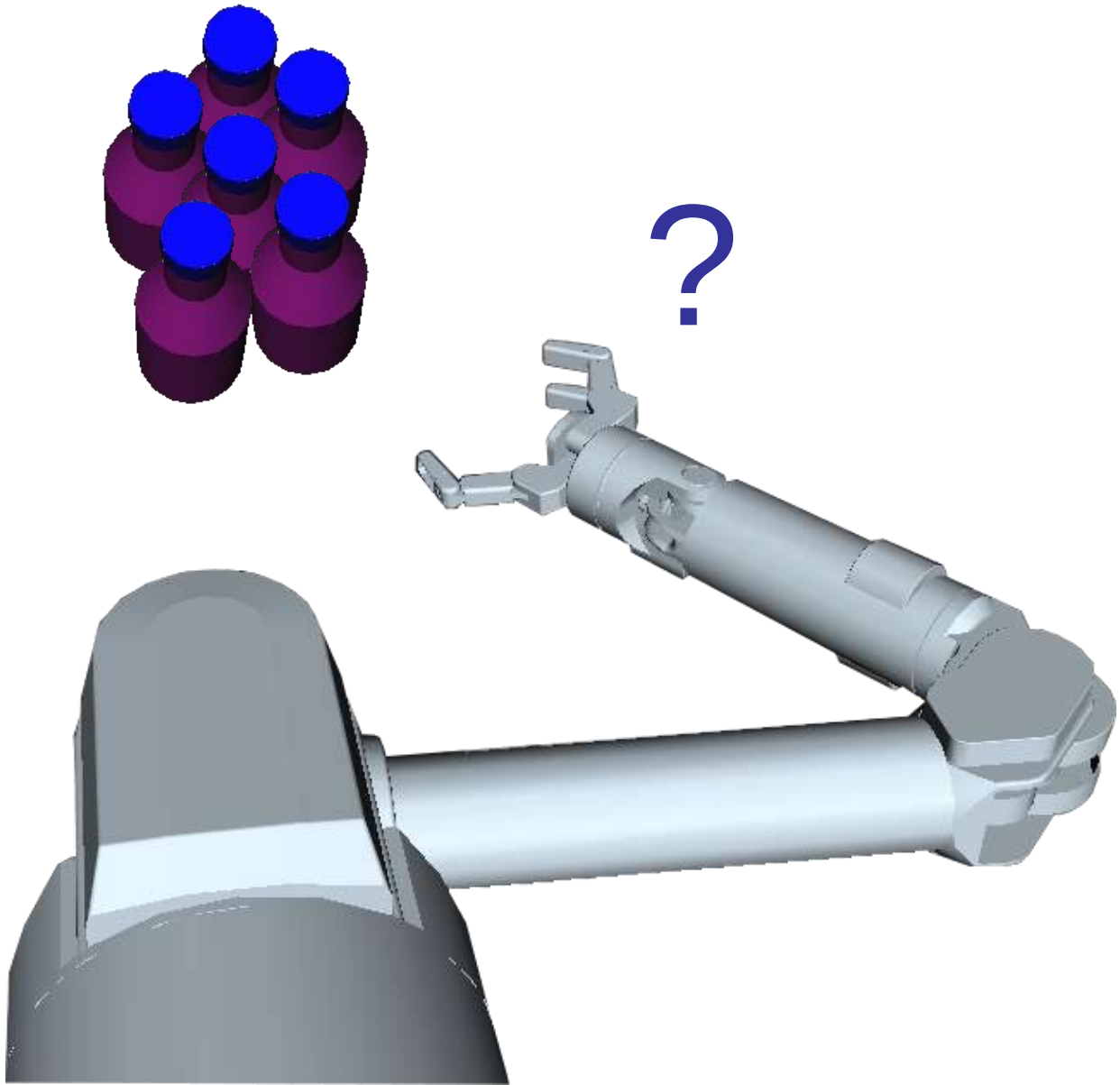
HRI

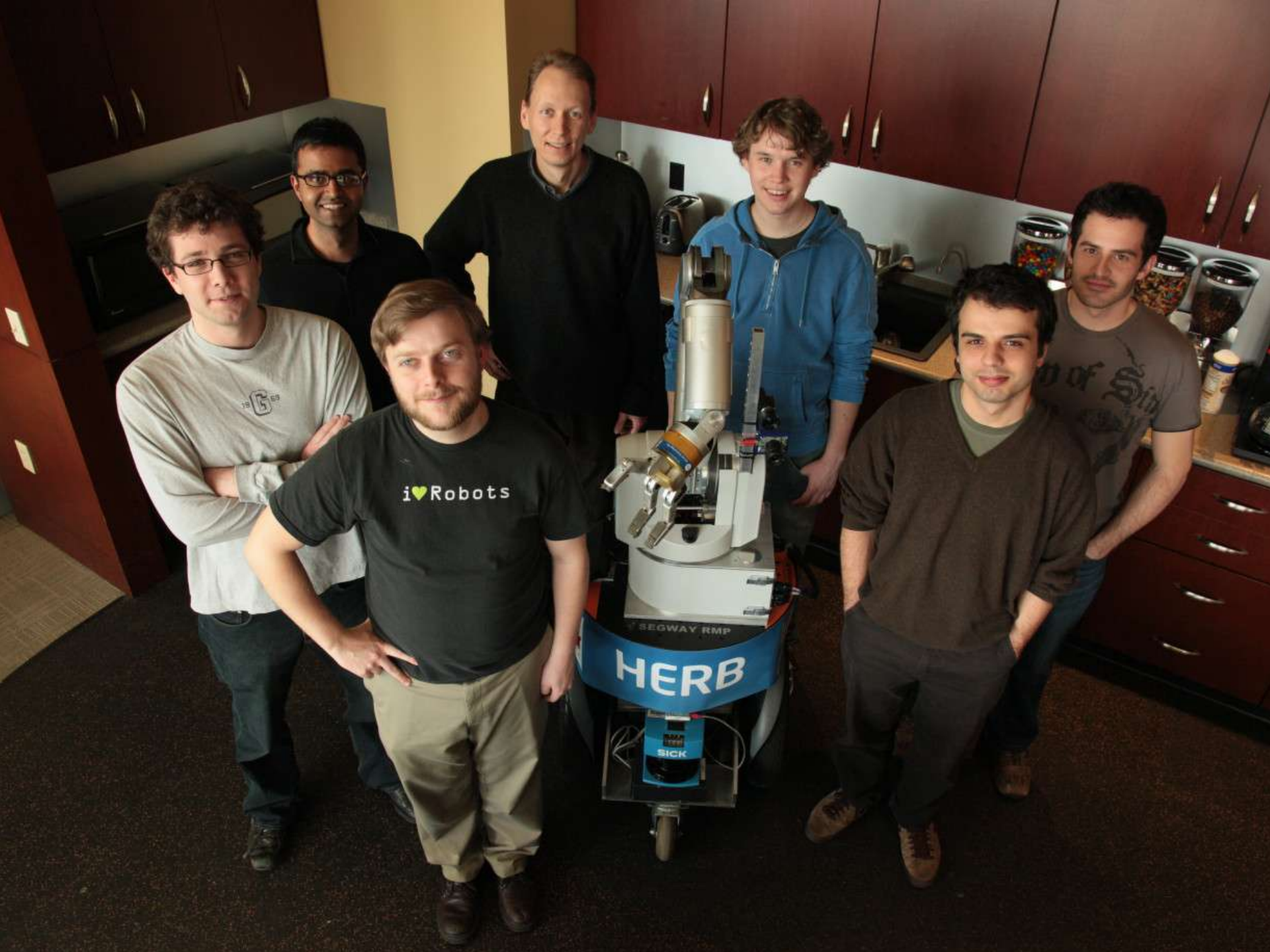
3D Modeling

Failure : Uncertainty



Failure : Uncertainty

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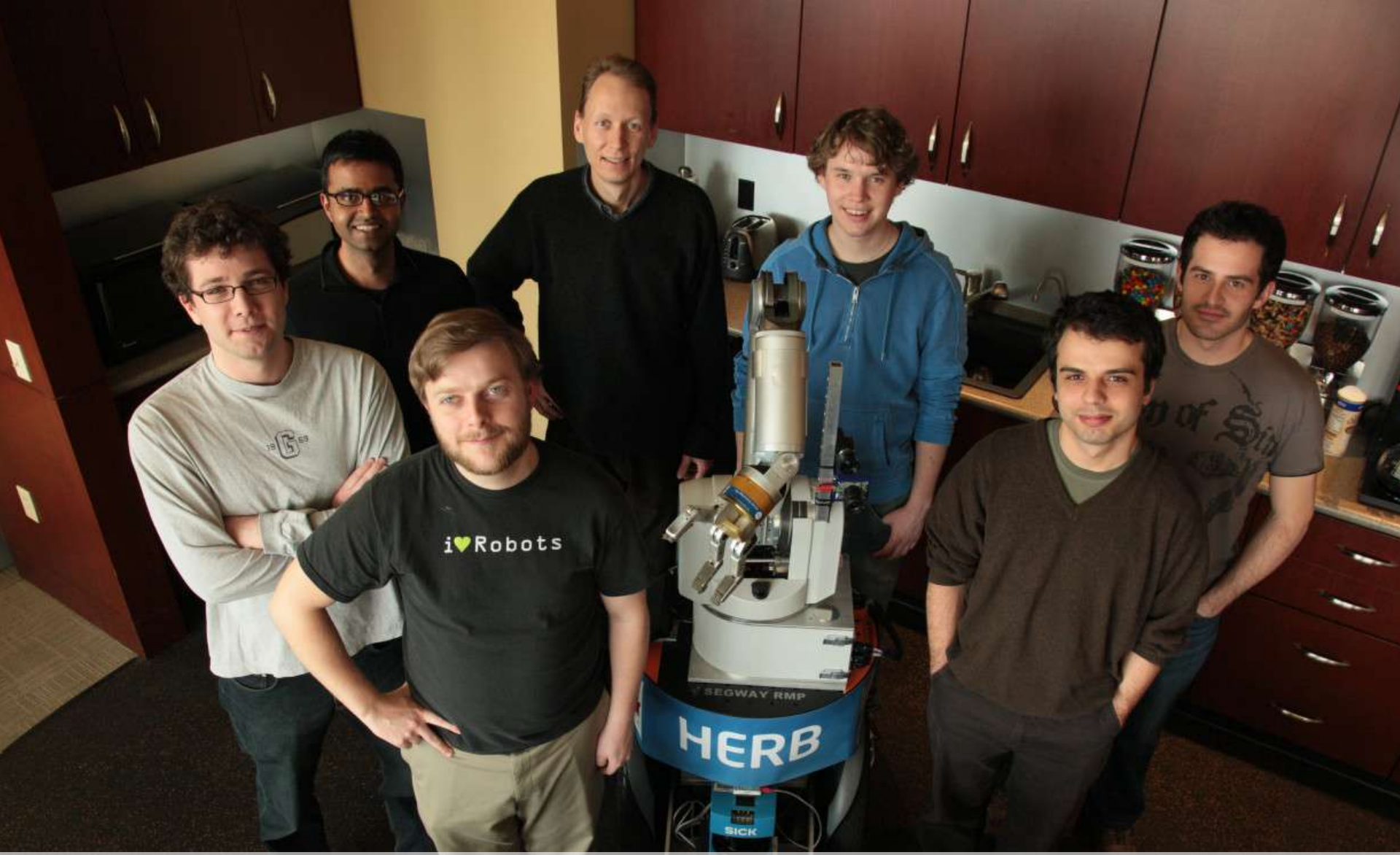
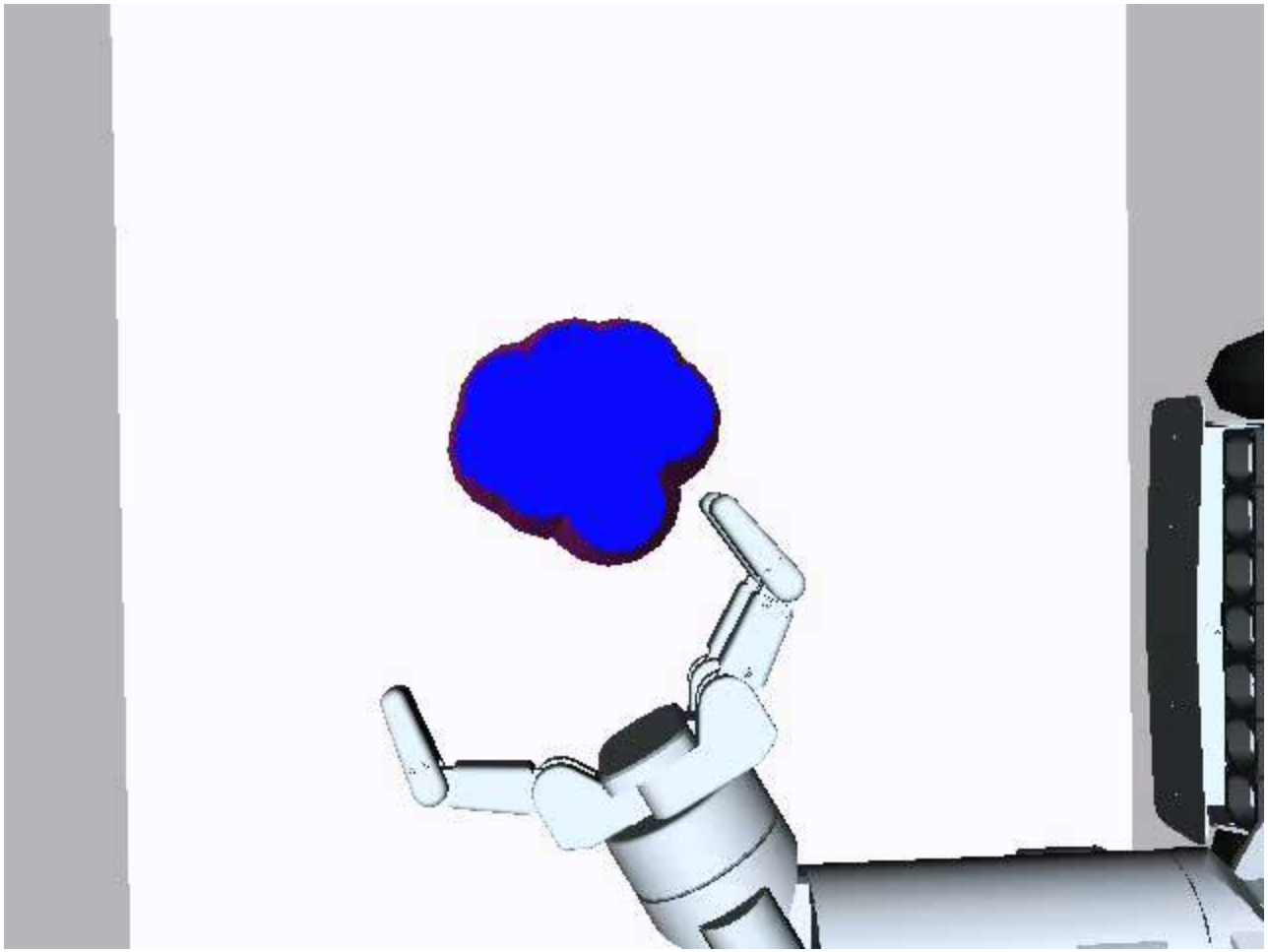


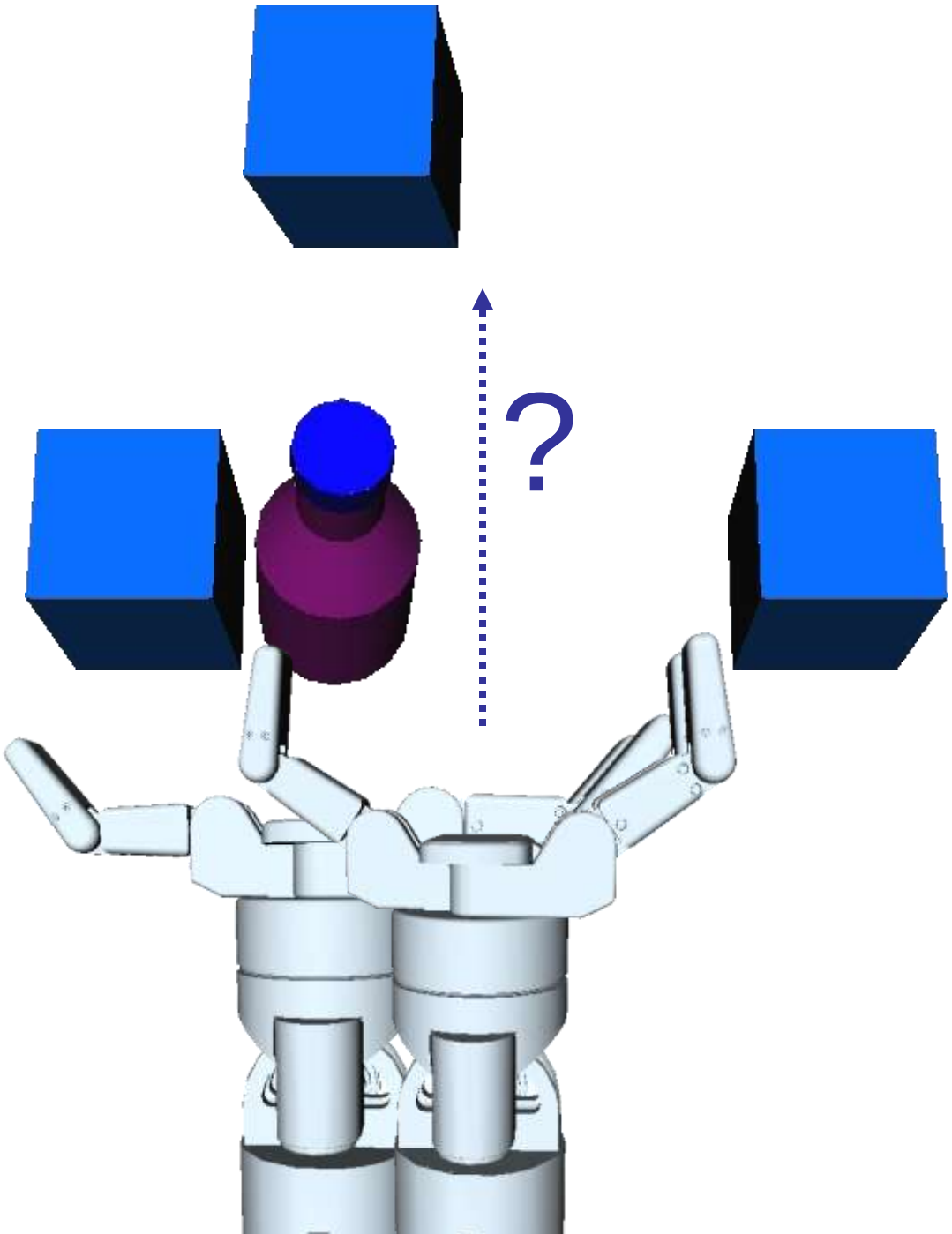
Departing Kinematics

Exploit the Mechanics of Manipulation to Funnel Uncertainty [Mason'81, Burridge et al.'99]



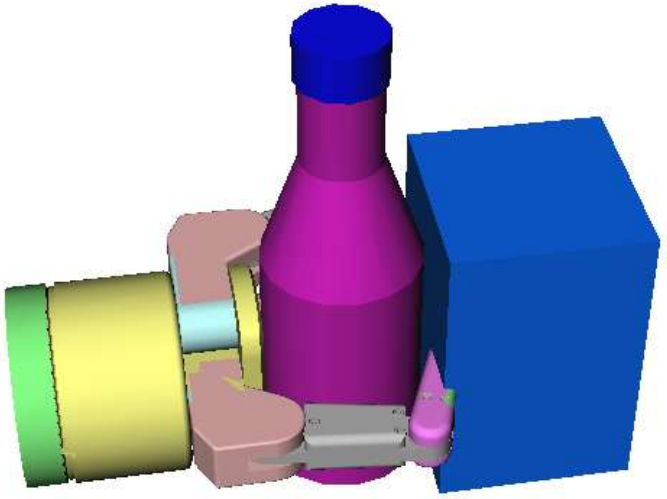
Why not just open
the hand wide and sweep?

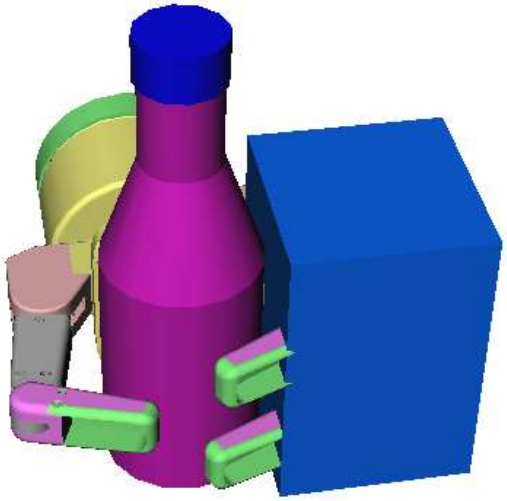
Clutter



Uncertainty
Clutter

Taste the muffin within.





Taste the muffin within.

The Details of Push-Grasping

Mechanics

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

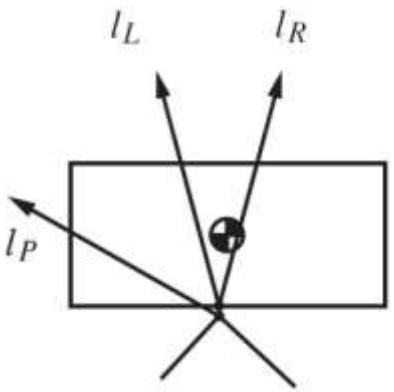
Method

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

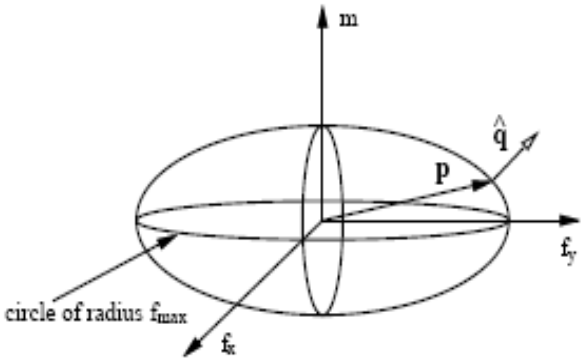
Validation

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

Quasi-Static Pushing



The Voting Theorem
[Mason'81]

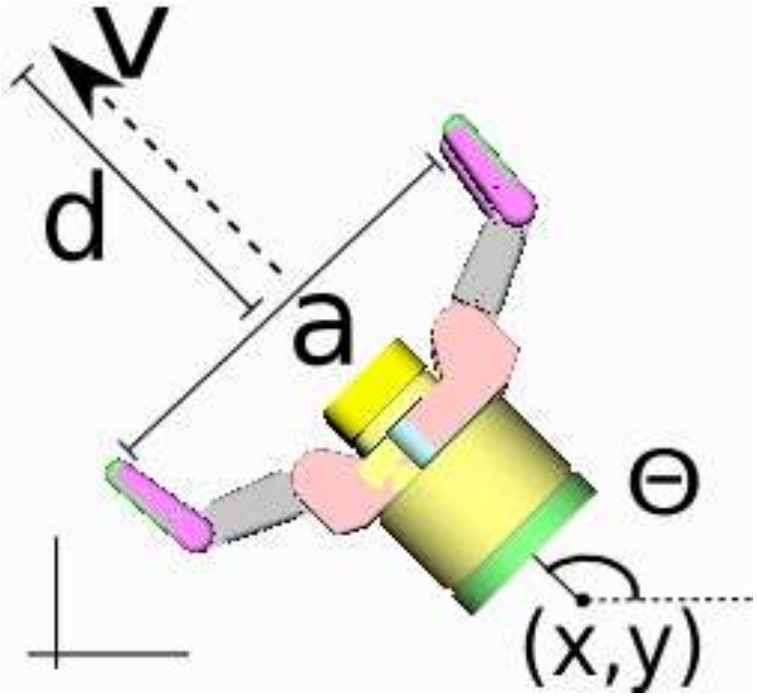


The Limit Surface
[Goyal et al.'91, Howe and Cutkosky'96]

How much should the robot know?

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

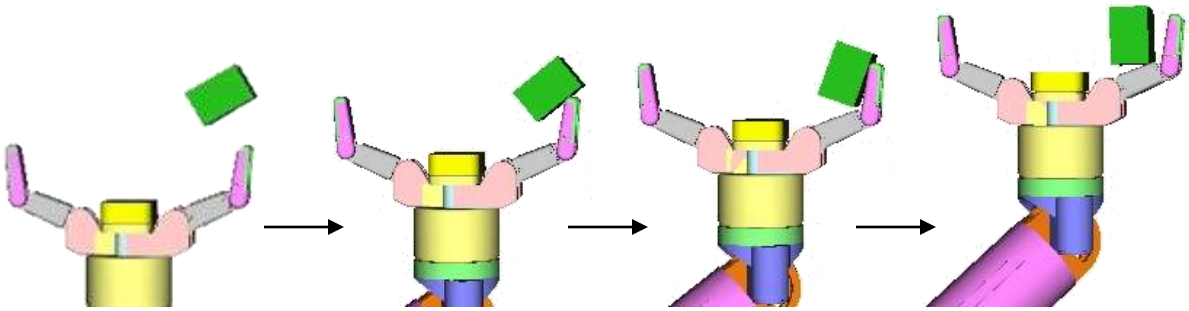
The Push-Grasp



- Hand pose: p_h=(x,y,**q**)
- Aperture: *a*
- Pushing direction: *v*
- Pushing distance: *d*

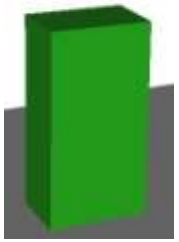
Push-Grasp: $G(p_h,a,d)$

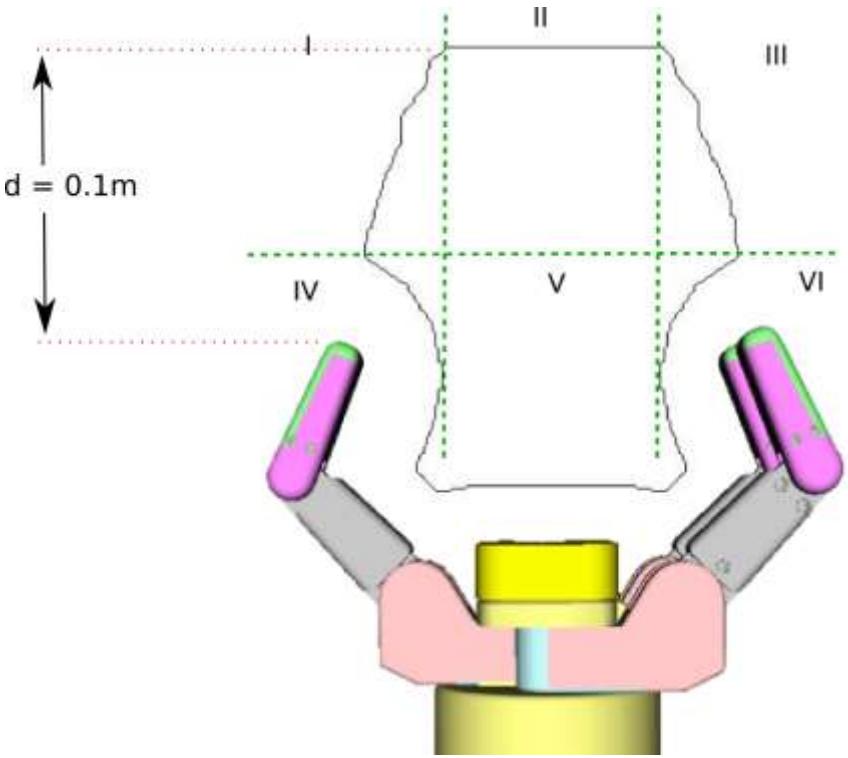
The Capture Region

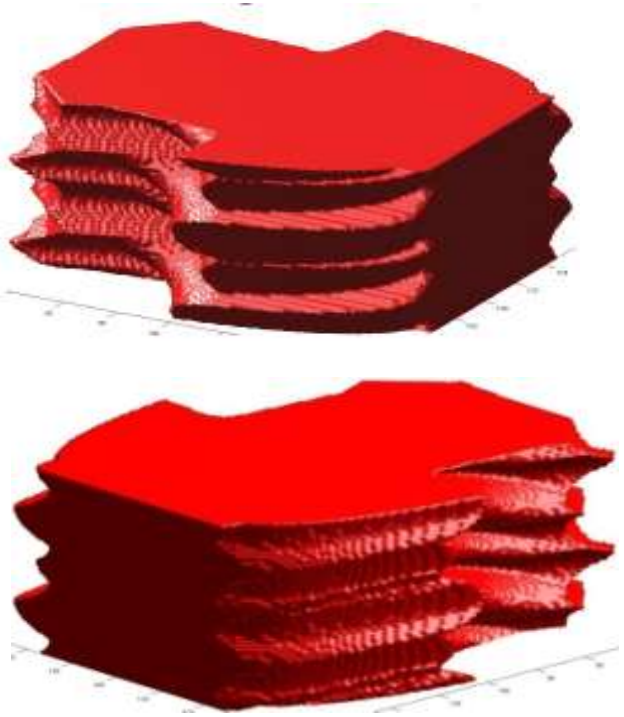


- Capture Region: *C(G,O)*
  - Set of all poses of object *O* that results in a successful push-grasp for *G*

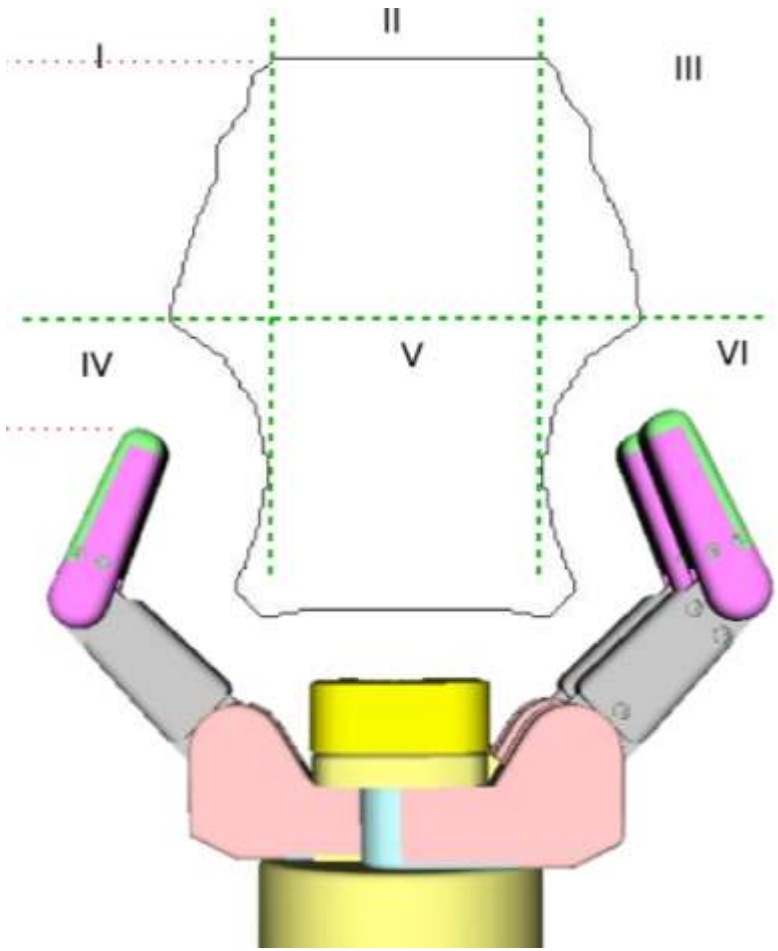
Example Capture Regions



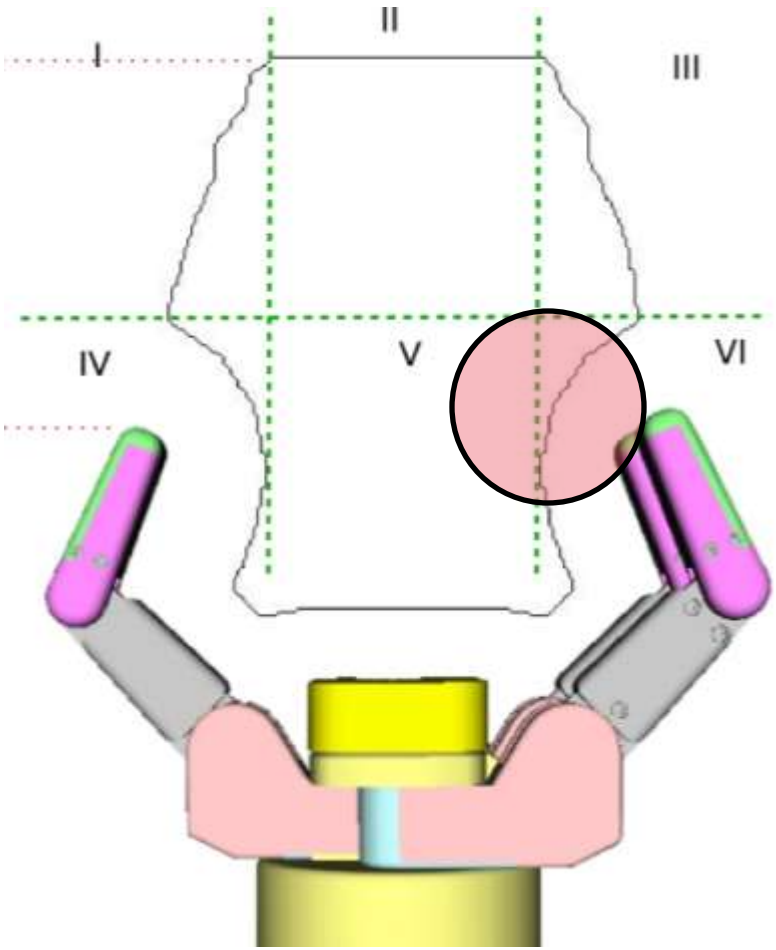




Understanding Capture Regions

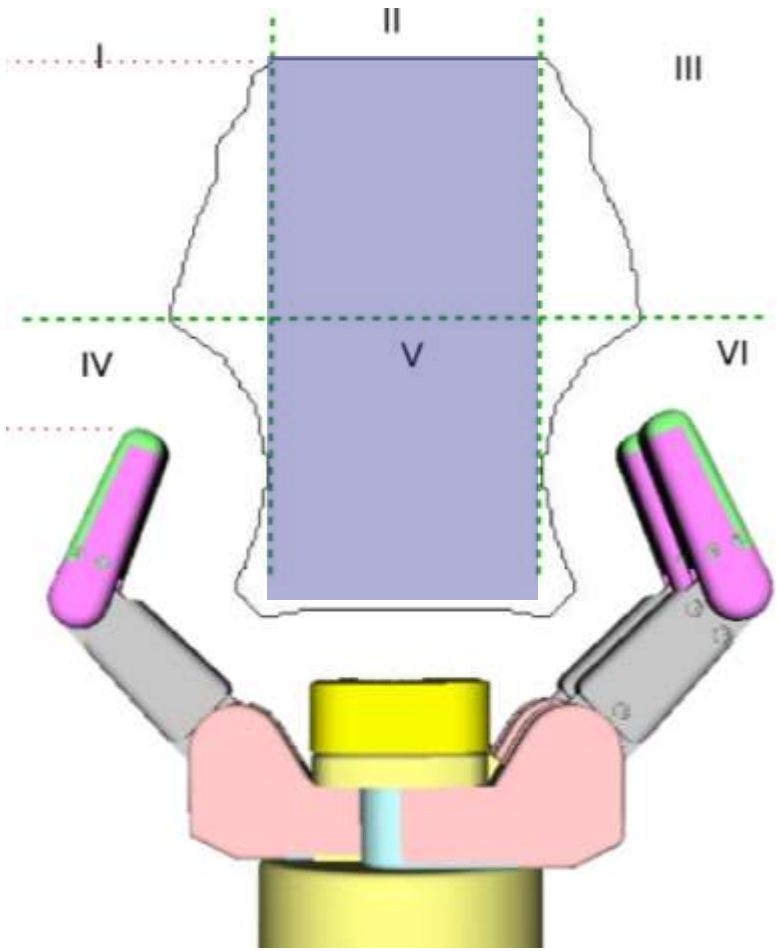


Understanding Capture Regions



IV, VI: Object contour

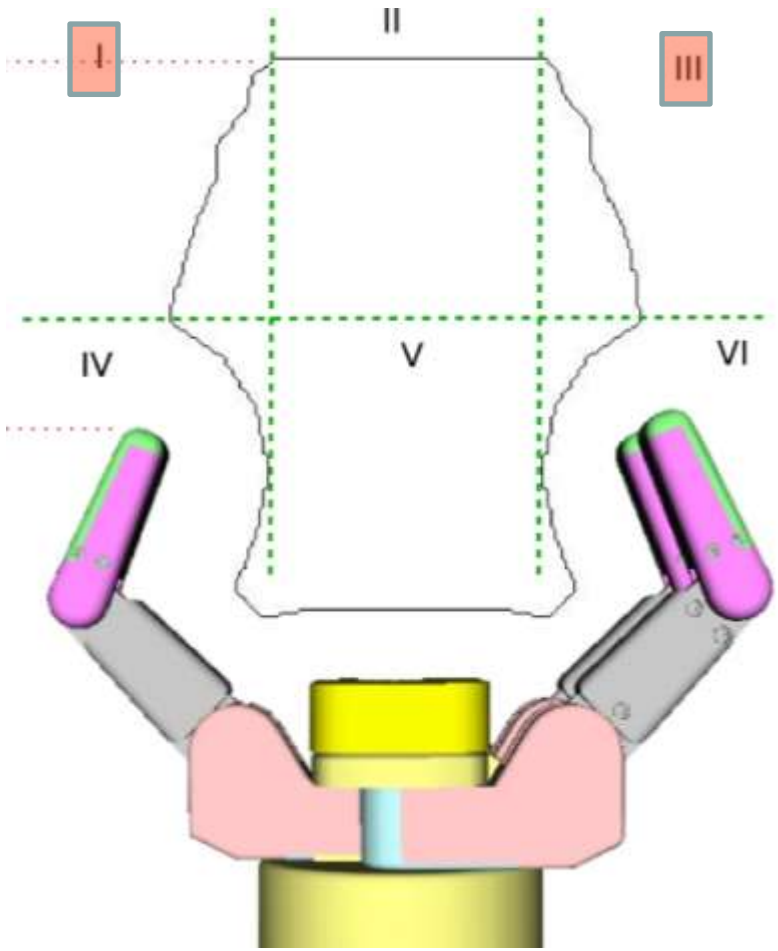
Understanding Capture Regions



IV, VI: Object contours

II, V: Caging regions

Understanding Capture Regions

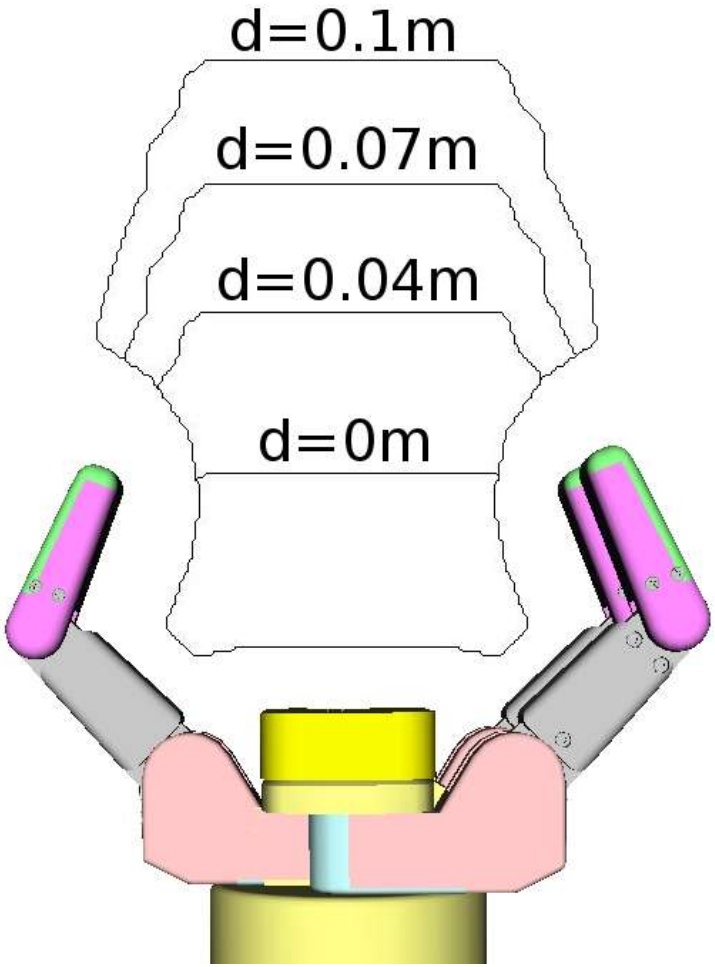


IV, VI: Object contours

II, V: Caging regions

I, III: Pushing regions

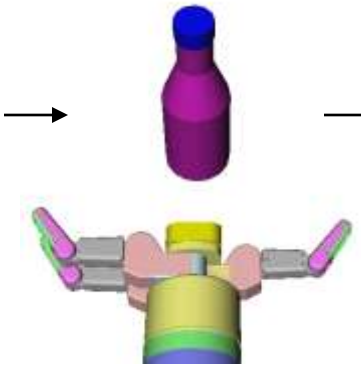
Understanding Capture Regions



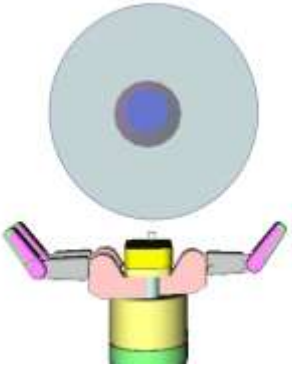
Addressing Object Pose Uncertainty

Vision

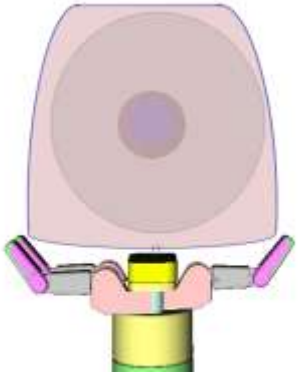
Reported pose



Uncertainty Region



Is included in capture region of a G?



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

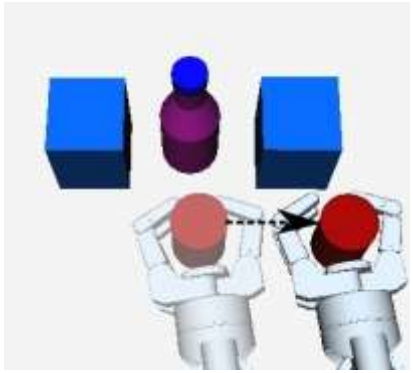
- Is our model of mechanics realistic? ✓
- **Does push-grasping work on a real robot?** ✓

HORIZON

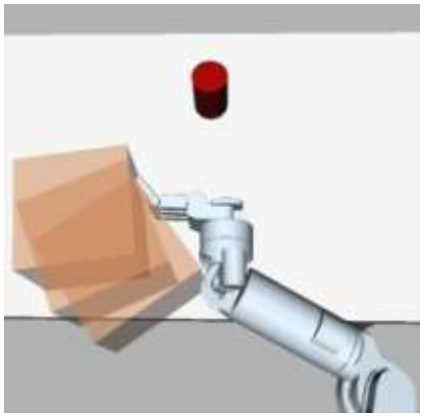
Polaner
Sugar Free
FIBER
STRAWBERRY
NEWMAN'S
ORGANIC
Marinara
1%
Lowfat Milk

HORIZON
Coca-Cola

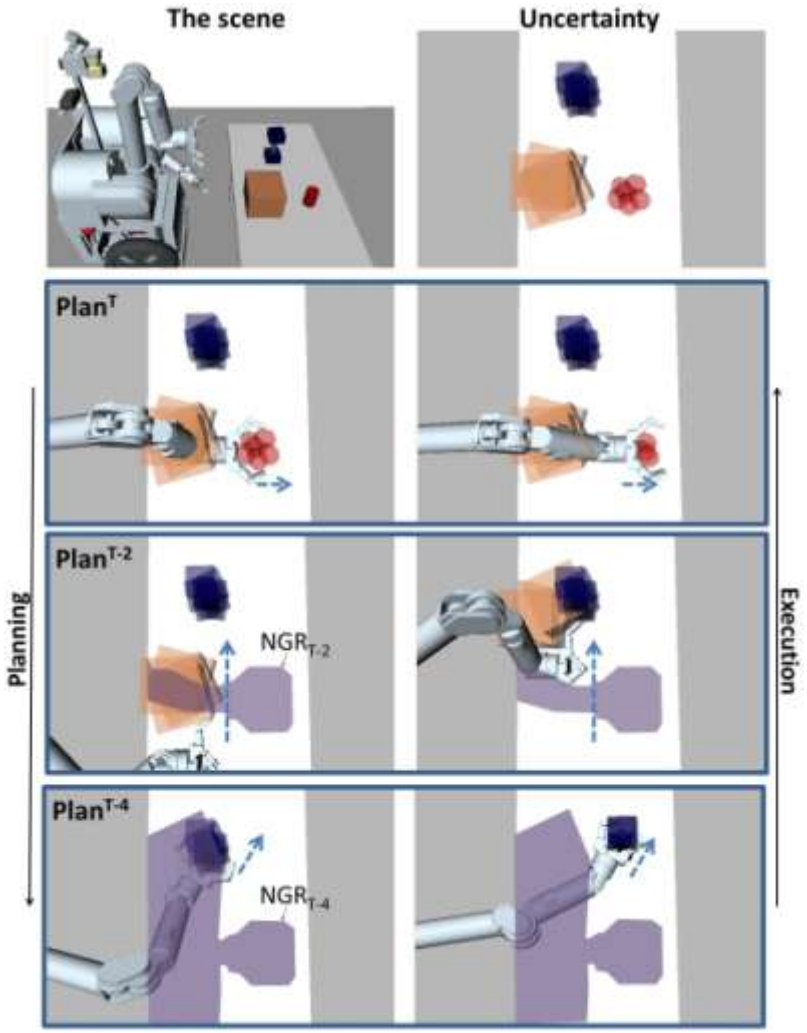
A Framework for Push-grasping in Clutter [RSS 2011 oral]



Slide-away



Sweep



Physical Manipulation

Geometric Search

Parallelism

Navigation

Learning

Control

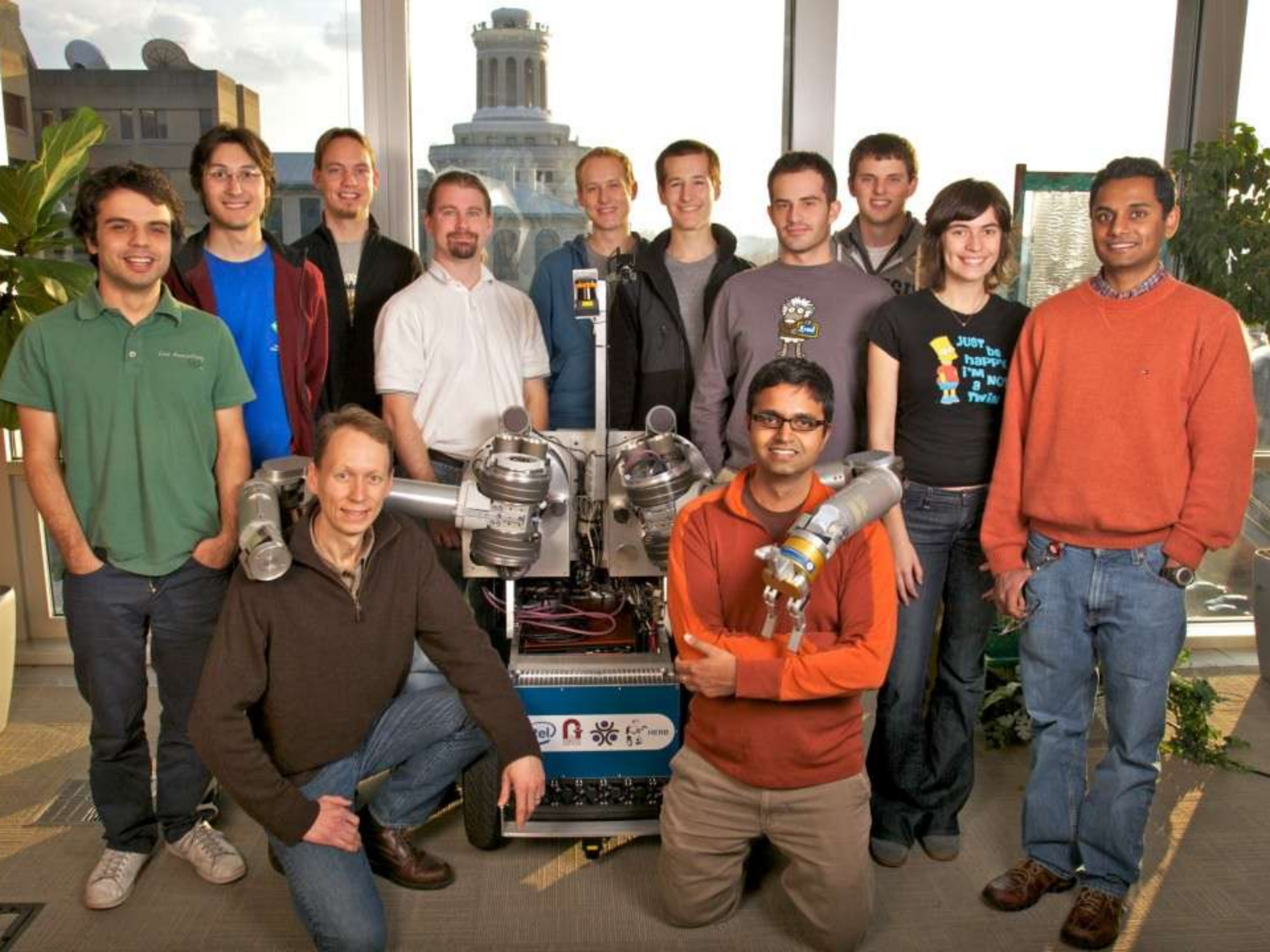
Perception

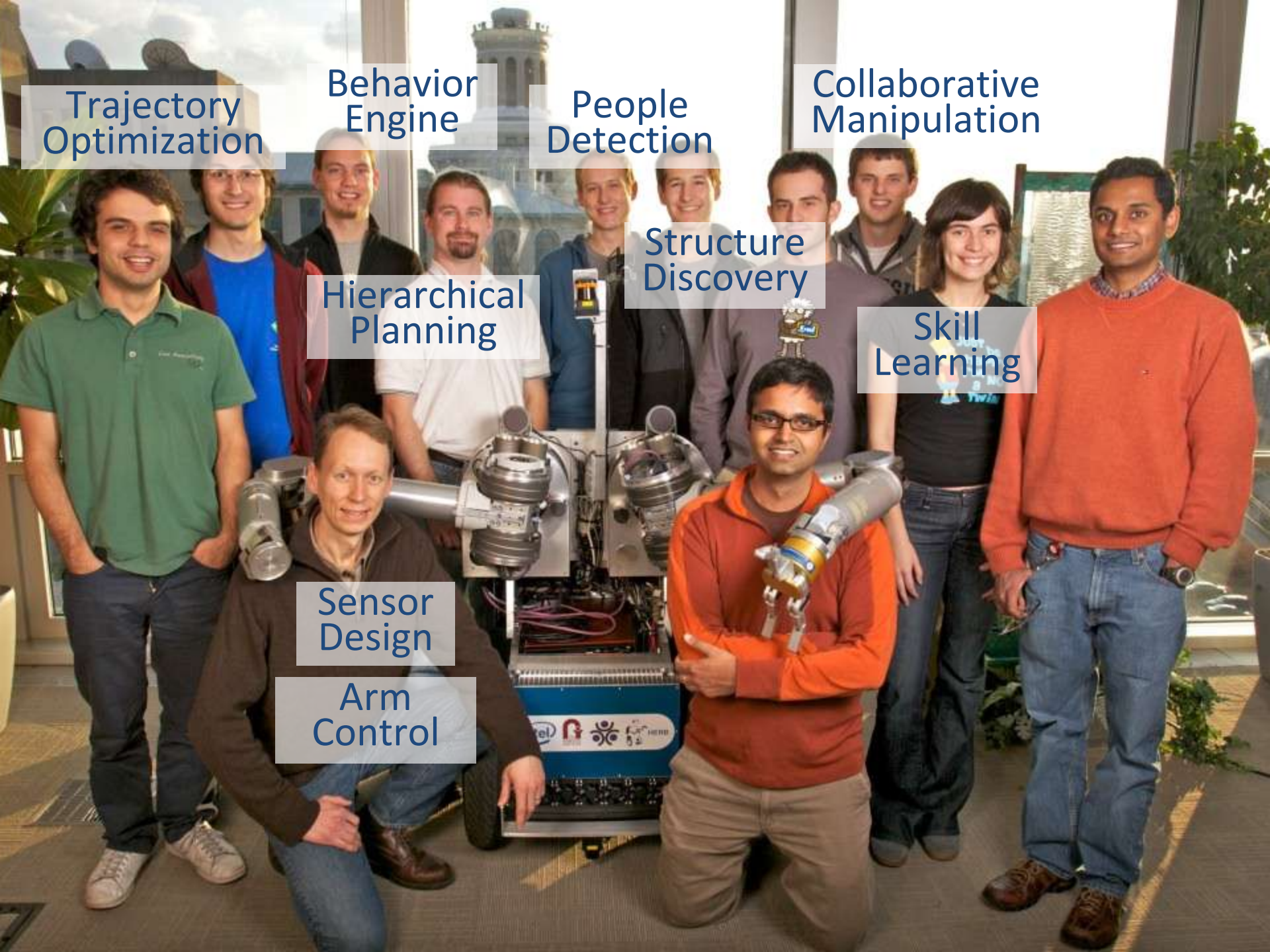
Manipulation

Systems

HRI

3D Modeling


JUST be happy I'M NOT a Twin


Trajectory Optimization
Behavior Engine
People Detection
Collaborative Manipulation
Structure Discovery
Hierarchical Planning
Skill Learning
Sensor Design
Arm Control

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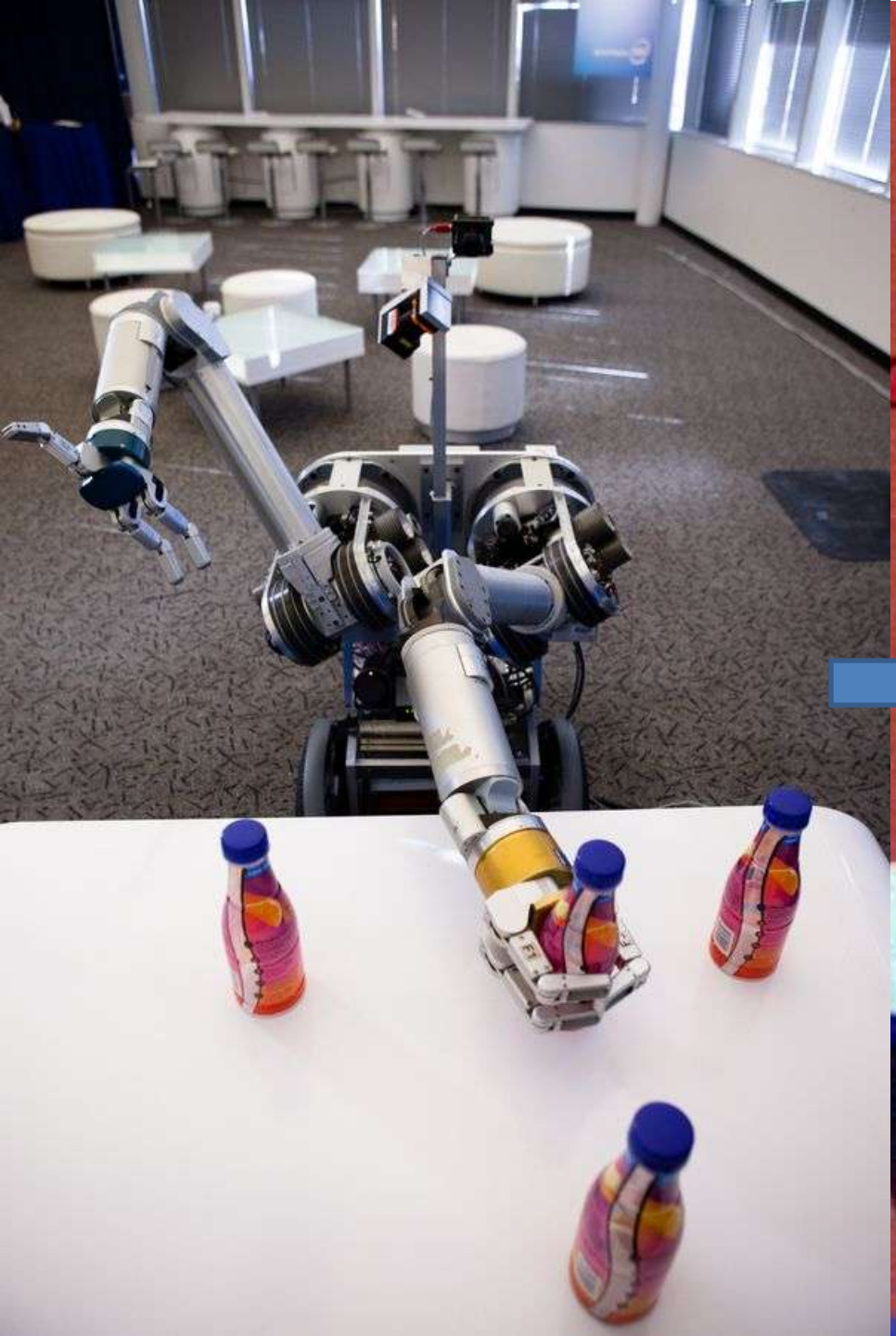
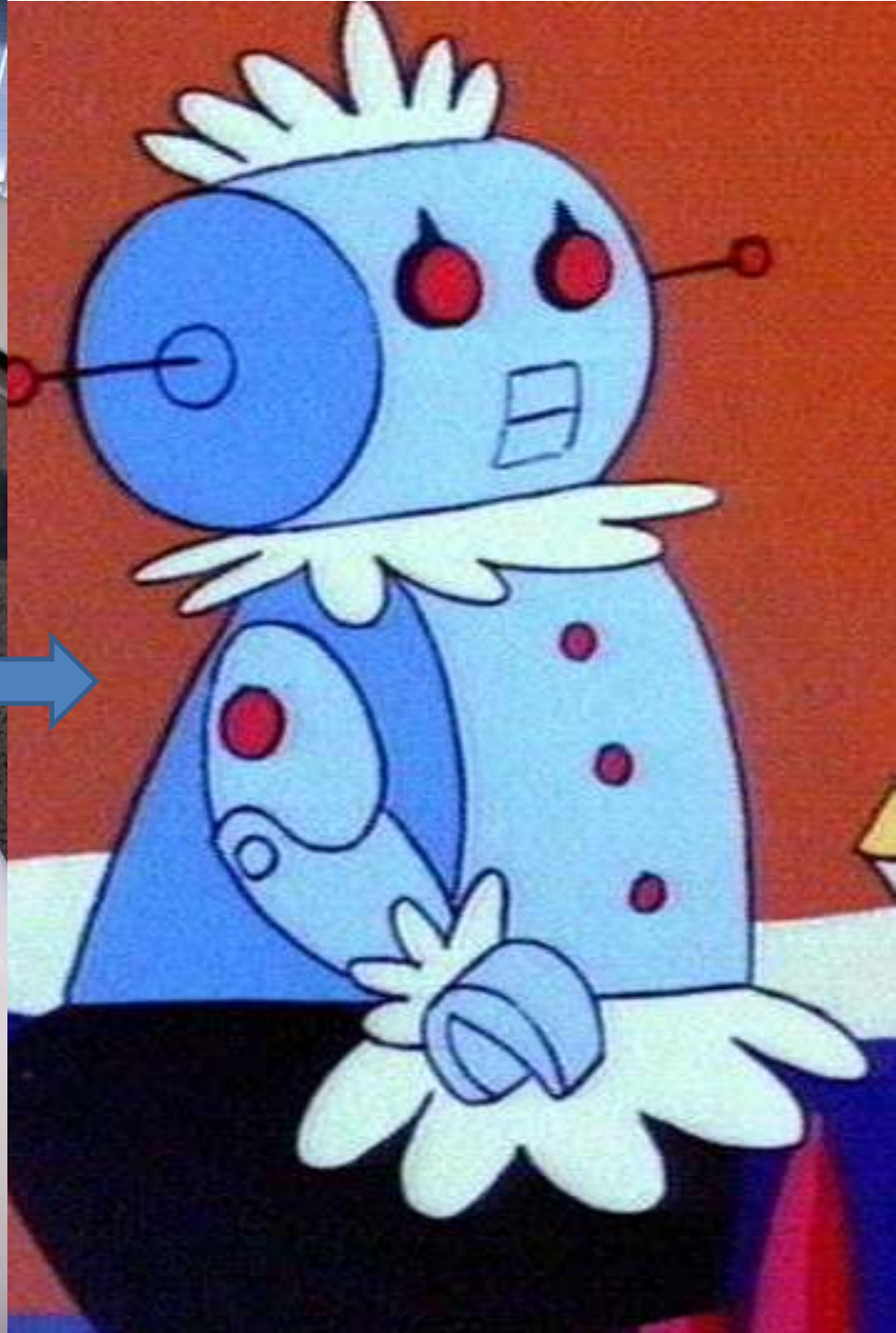
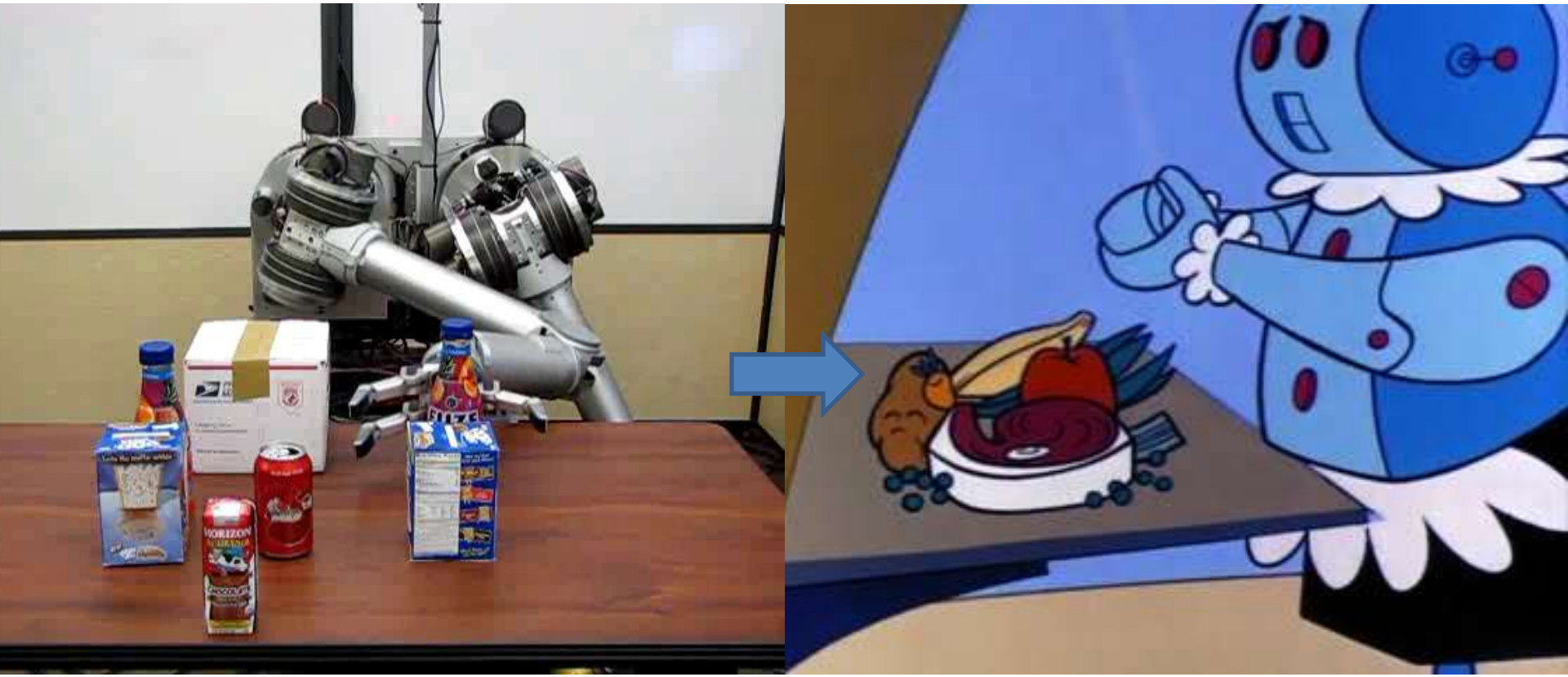
  World's most advanced robots
- **CBS**
  Robots Soon To Become Part Of Home, Work Life
- **Popular Science**
  Rise of the Helpful Machines: Meet 10 of the most advanced human-assist 'bots from around the world
- **Fast Company**
  Intel's Robot Butler Serves, Clears, and Does Dishes
- **Wired Magazine**
  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

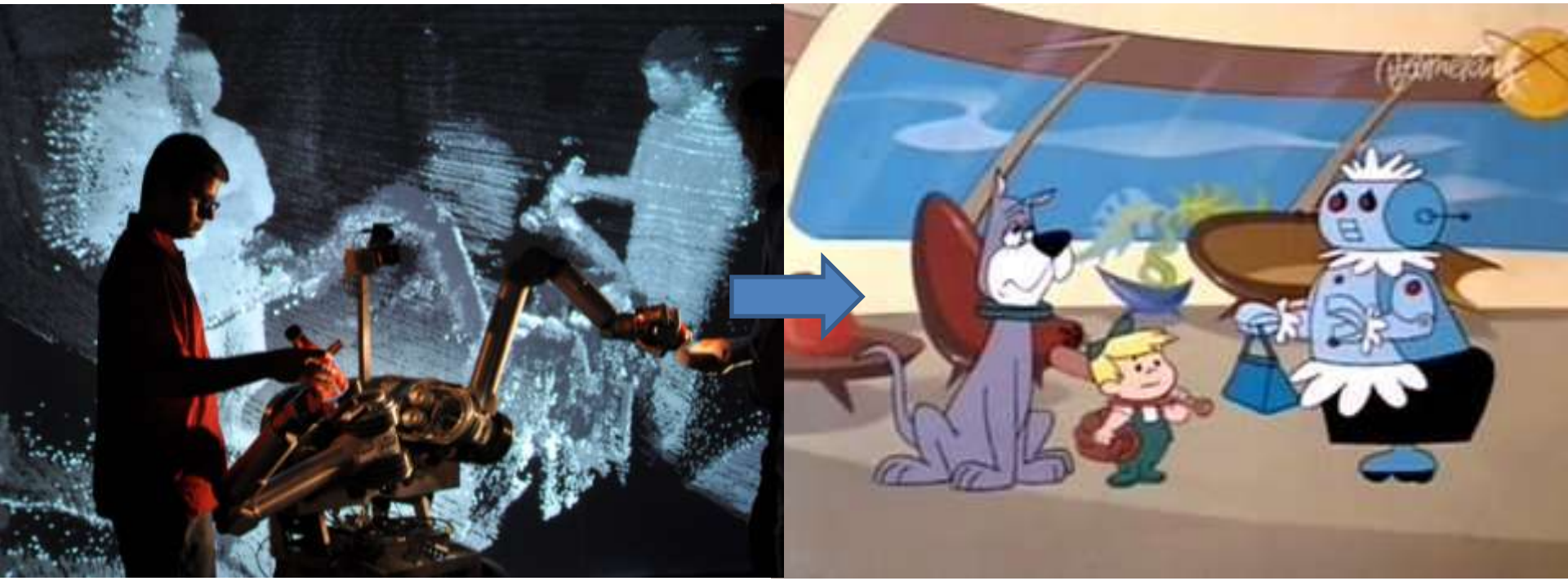




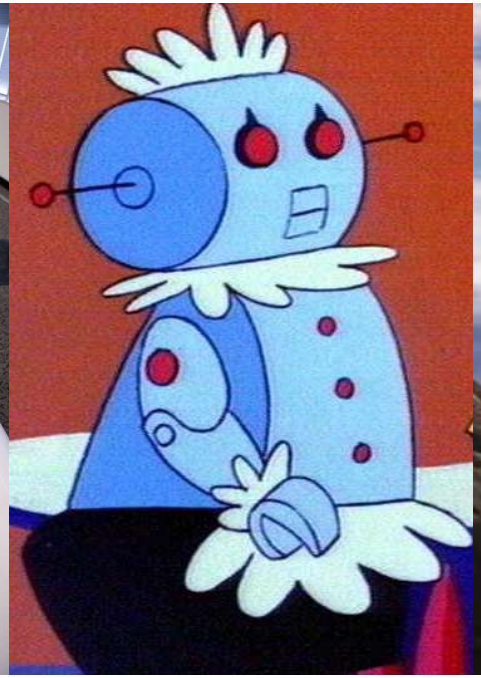
Departing Kinematics



Collaborative Manipulation



Manipulator Design



...

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HRI

3D Modeling

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

PRL talks at ICRA 2011

Addressing Cost-Space Chasms in Manipulation Planning
Dmitry Berenson, Thierry Simeon, Siddhartha Srinivasa
Manipulation Planning I – ThA105, 08:35-08:50

Manipulation Planning with Goal Sets Using Constrained Trajectory Optimization
Anca Dragan, Nathan Ratliff, Siddhartha Srinivasa
Manipulation Planning I – ThA105, 09:20-09:35

Structure Discovery in Multi-Modal Data: A Region-Based Approach
Alvaro Collet, Siddhartha Srinivasa, Martial Hebert
Visual Servoing I – ThP111, 14:40-14:55

A Framework for Push-Grasping in Clutter
Mehmet Dogar, Siddhartha Srinivasa
Workshop on Manipulation Under Uncertainty, Friday

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