Robot-world physical interactions:
Challenges, Solutions, and Research directions

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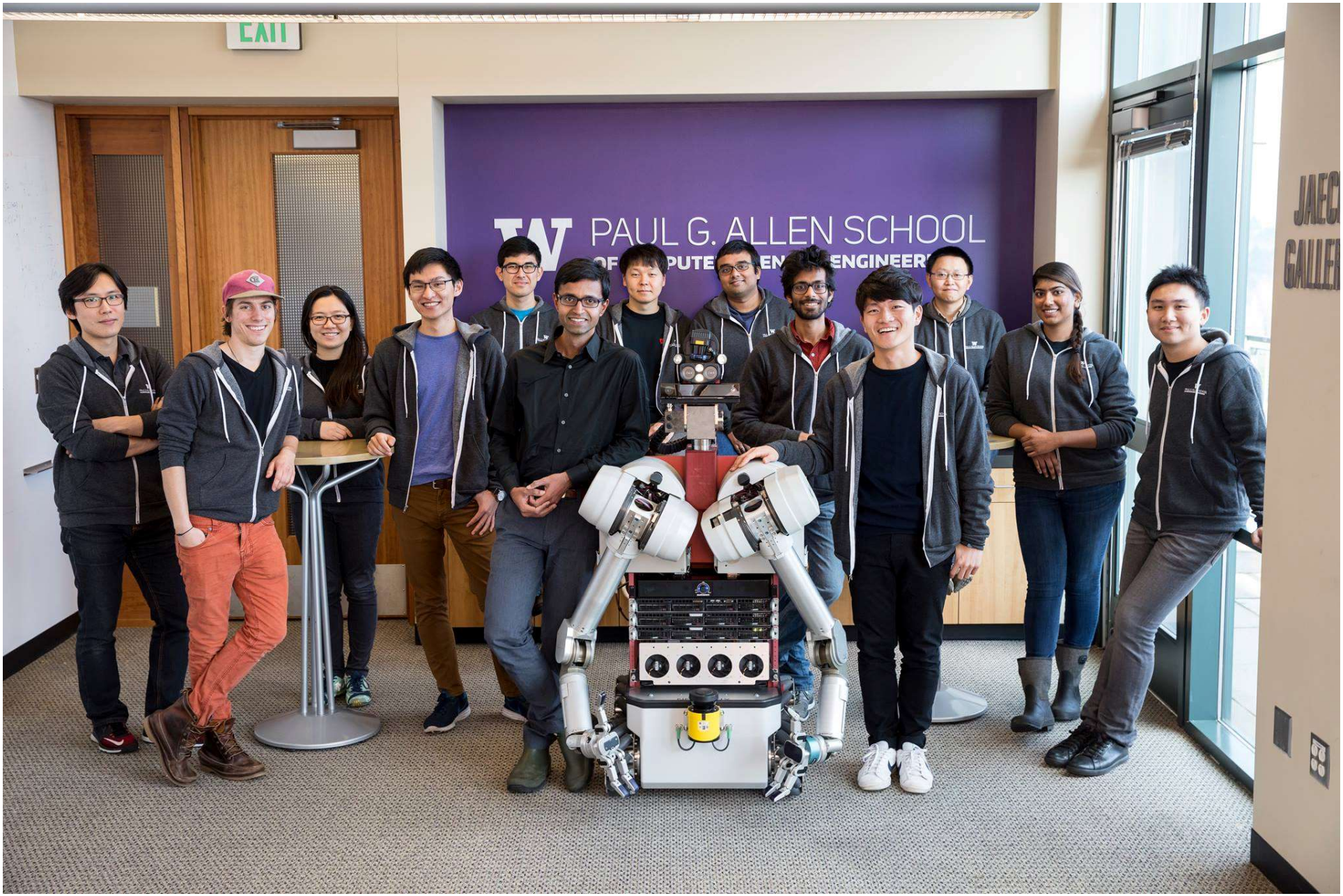
Many slides courtesy of Siddhartha S. Srinivasa


EXIT
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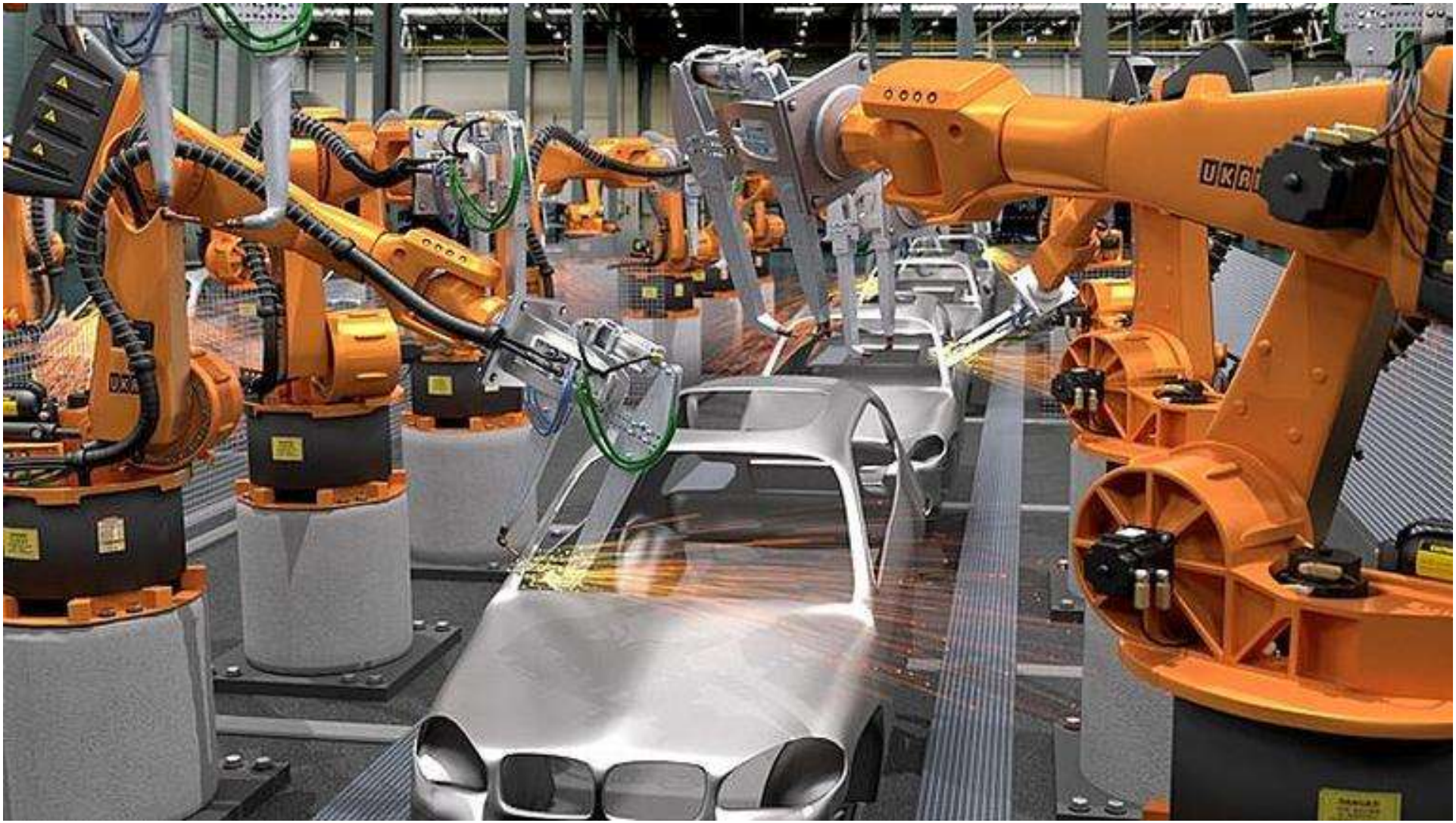
Manipulation

Easy?



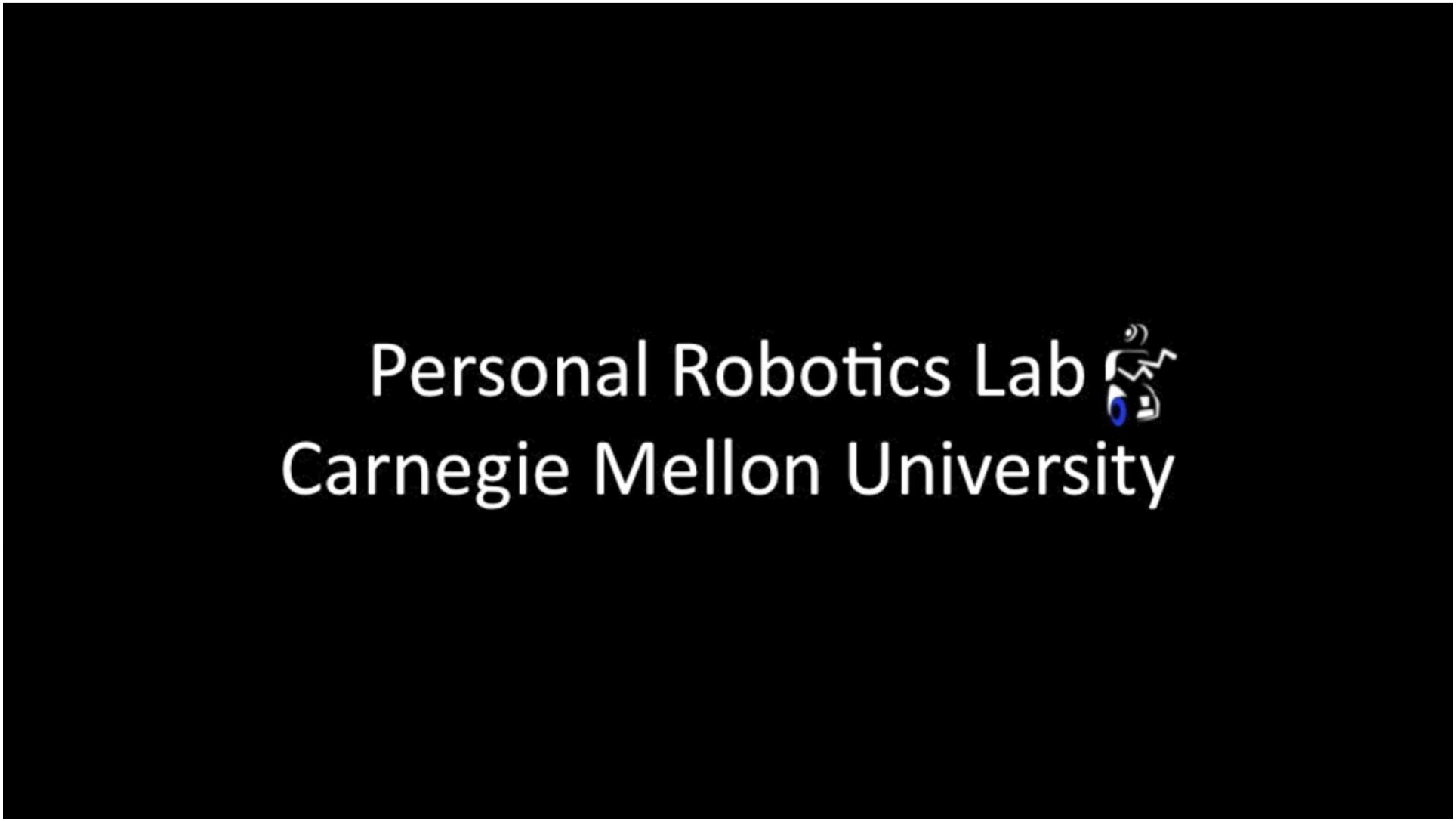
What's easy? What's hard?

Hard!

The Sense-Plan-Act Paradigm under Uncertainty

HERB: Home Exploring Robot Butler

A Mobile Manipulation Testbed Built by PRL



Physical Manipulation

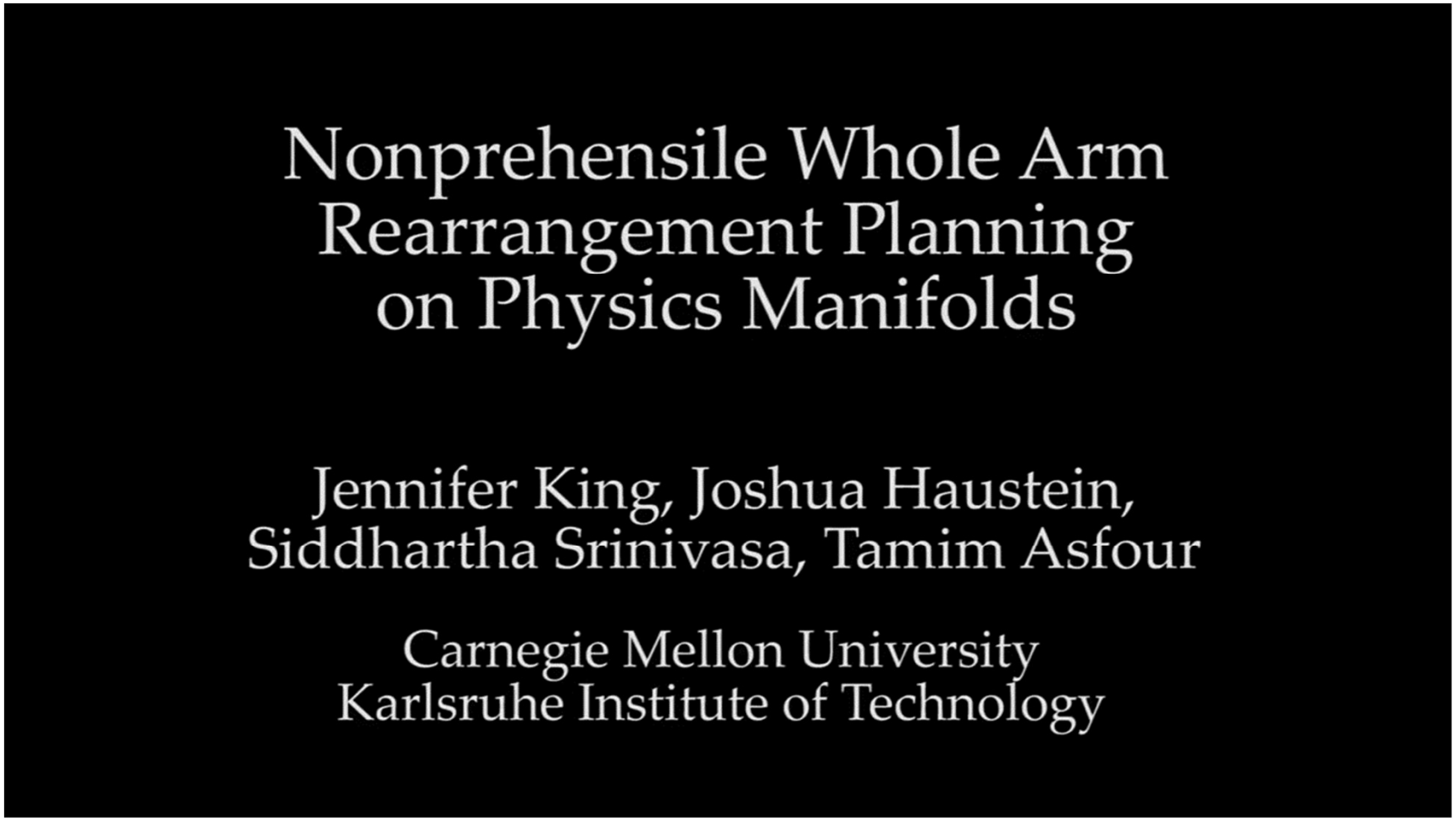
Geometric Search

Physics-Based Manipulation

Manipulation under Uncertainty

Physics-Based Manipulation

Manipulation under Uncertainty



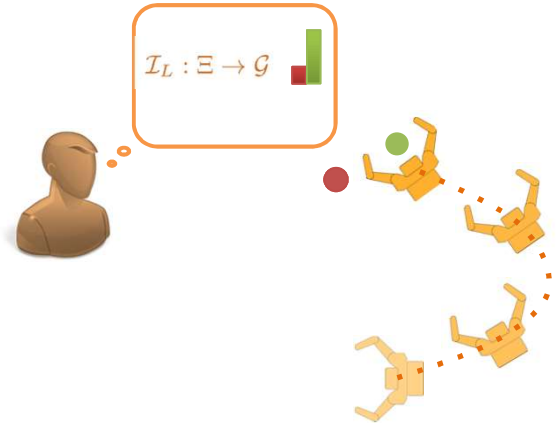
Manipulation with and around people

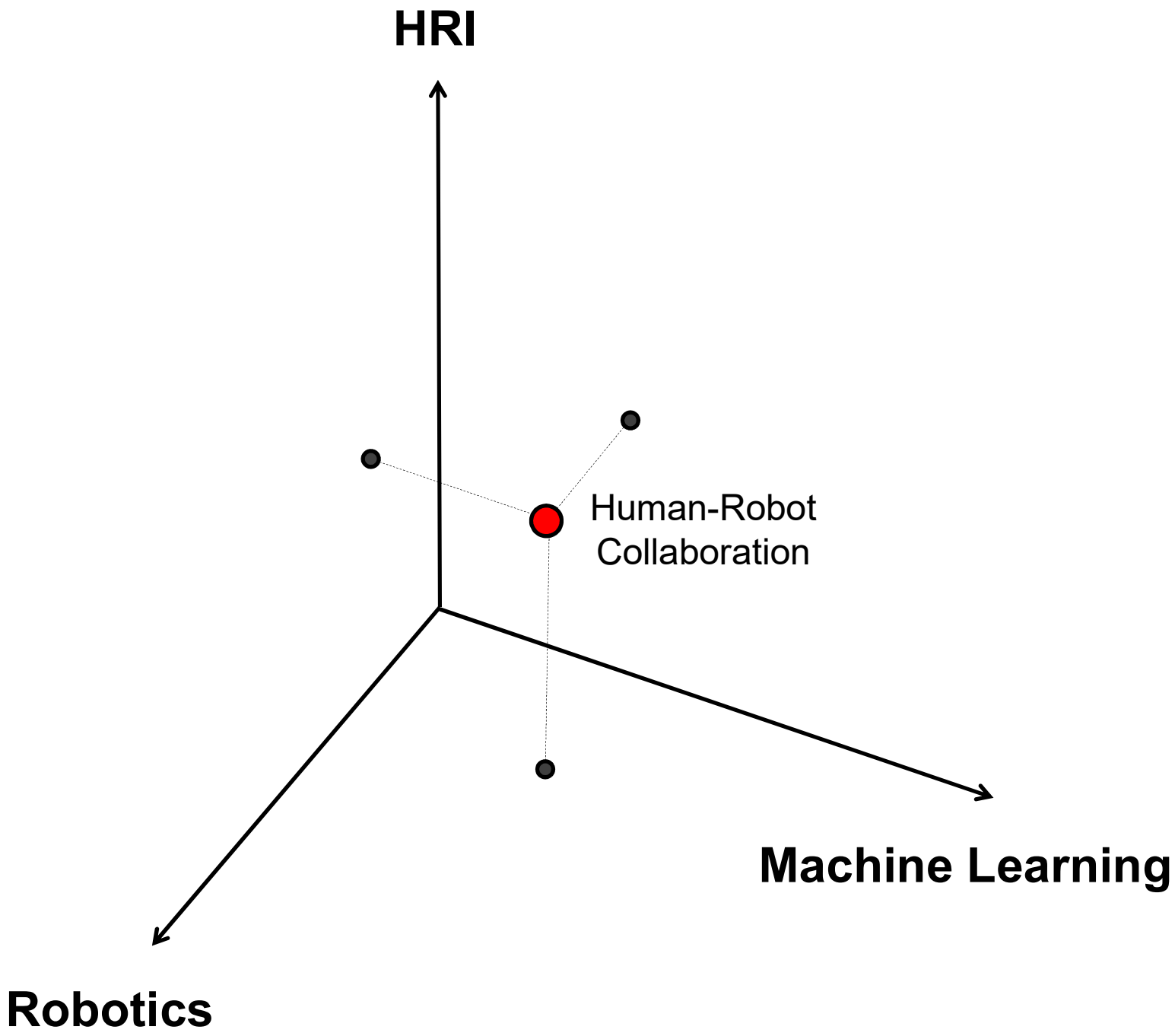
Physical Manipulation

Geometric Search

Human-Robot Collaboration

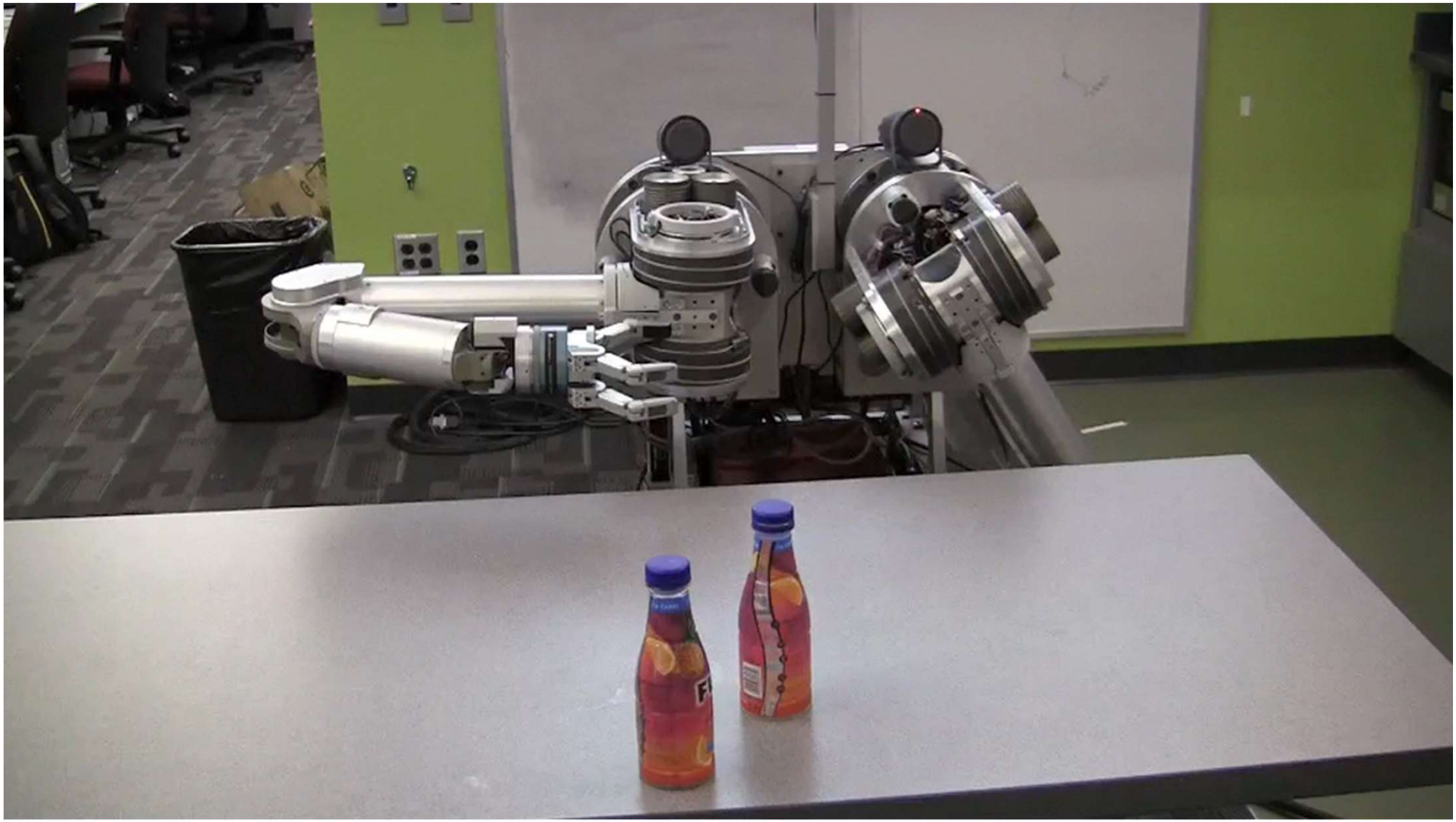
Optimal Control




HRI
Human-Robot
Collaboration
Machine Learning
Robotics

Legible Robot Motion

Mathematical Models for Human Robot Interaction



Deceptive Robot Motion

Mathematical Models for Human Robot Interaction

Assistive Feeding

Autonomous Robot Feeding with Assistive Dexterous Arm (ADA)

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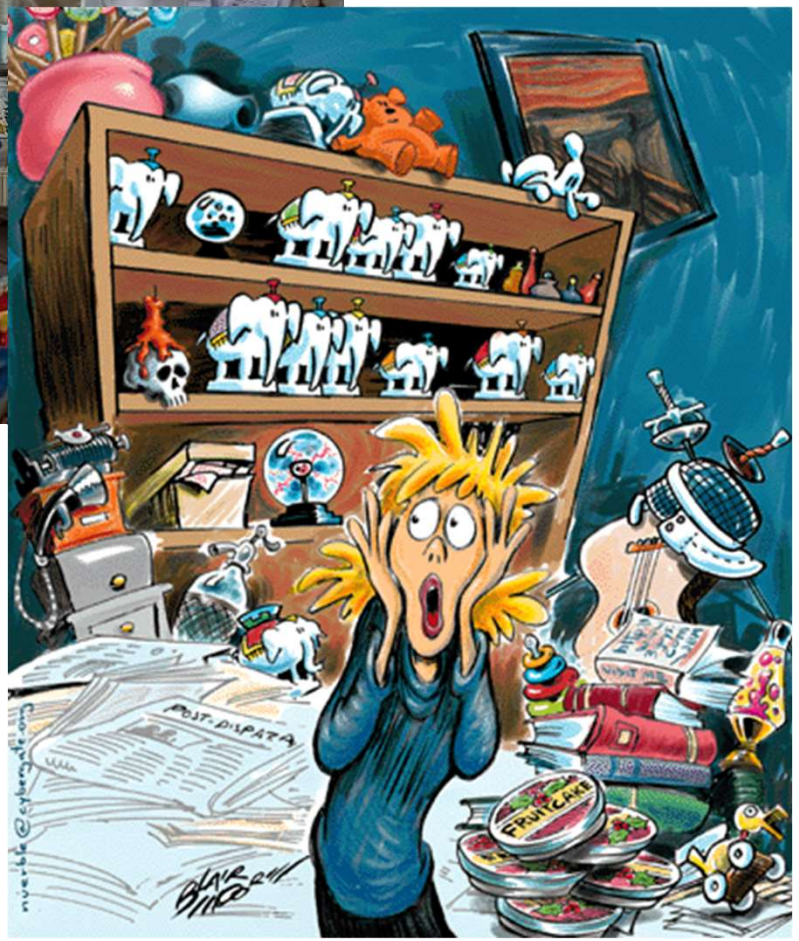
Food Manipulation: Deformable objects

Food Manipulation: Deformable objects

Hard!

Hard!



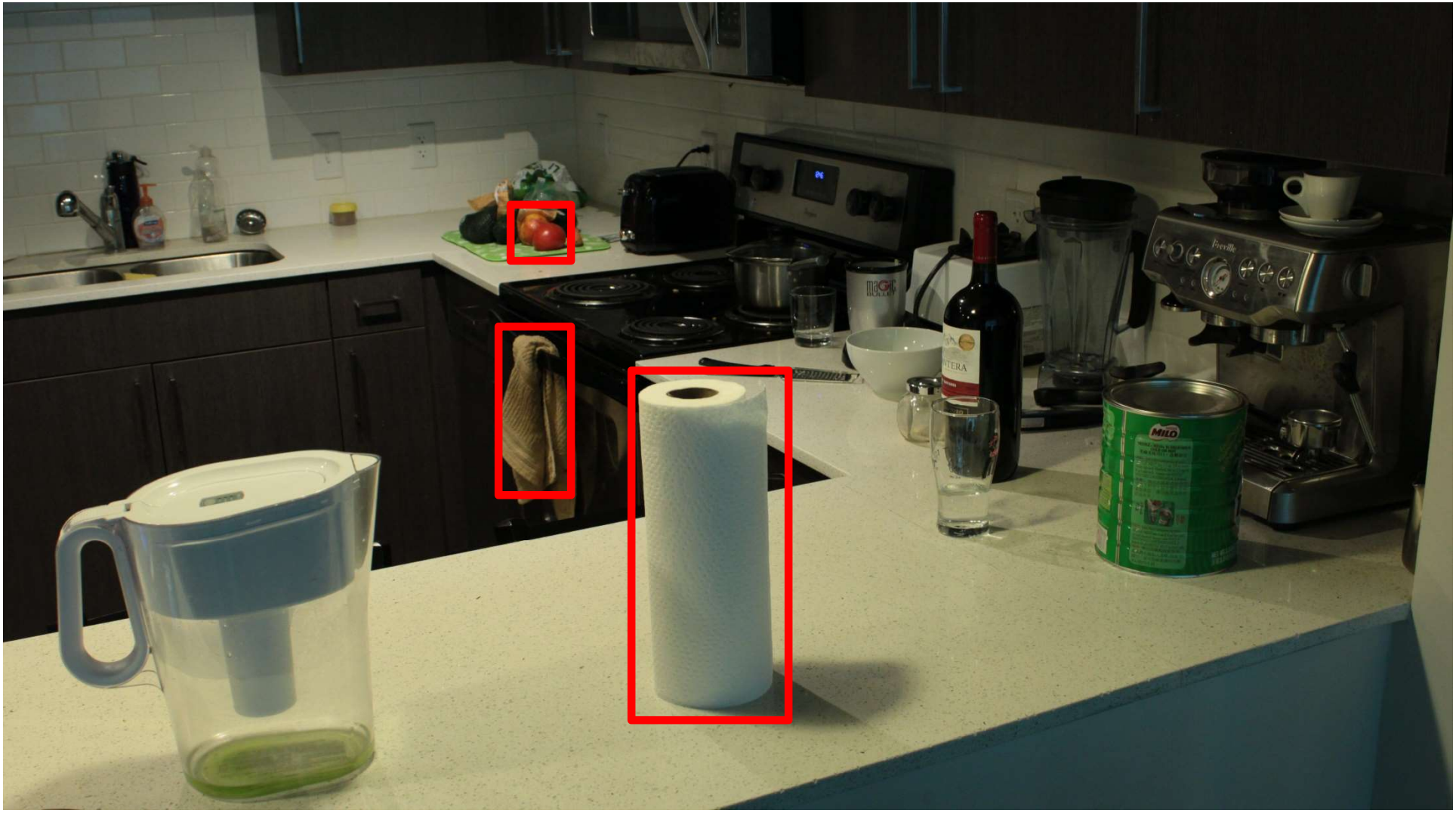
Clutter: Contact is inevitable!

What properties are relevant?

Let’s take an example environment…

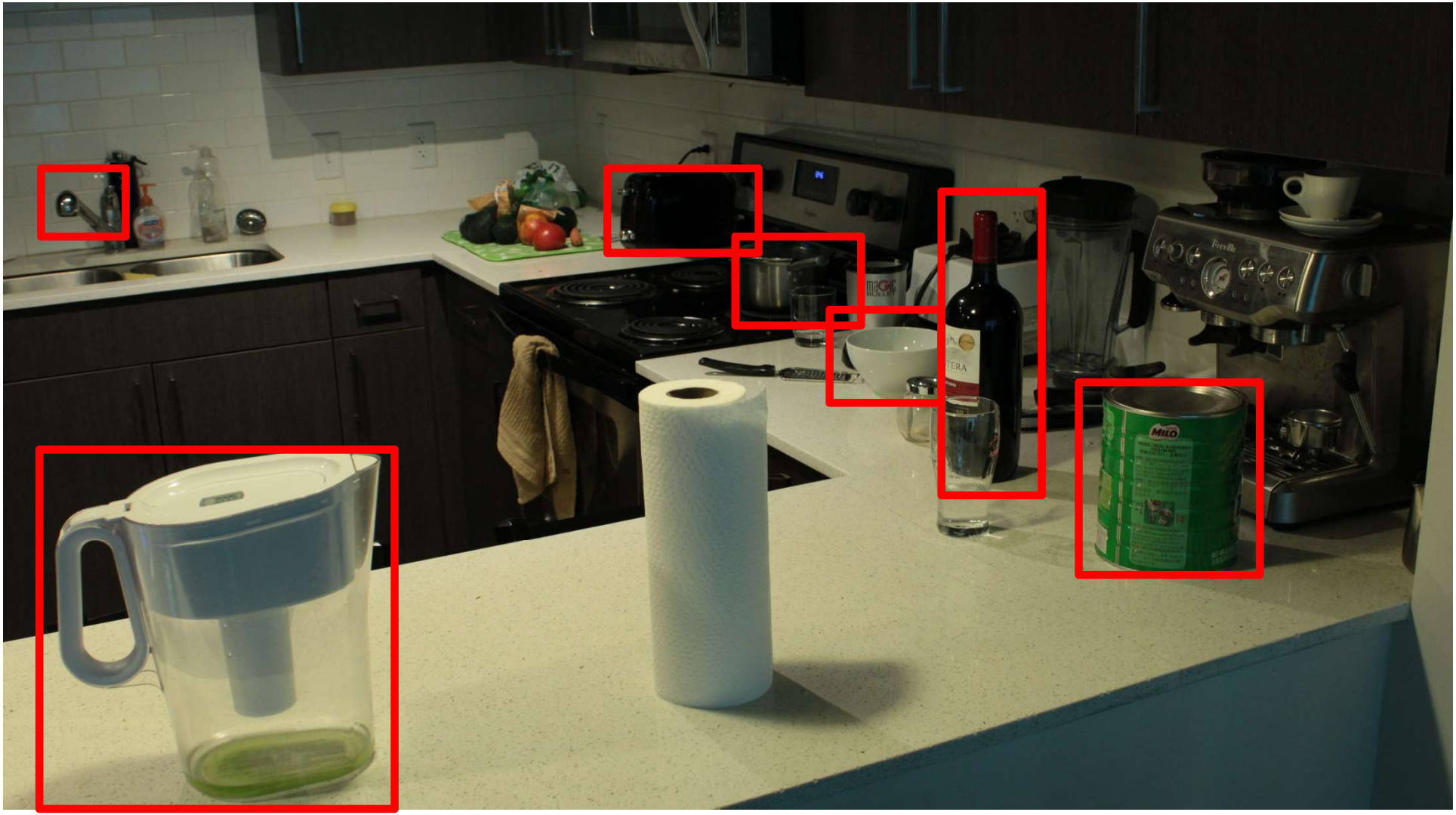
A Kitchen

Let's take an example environment…



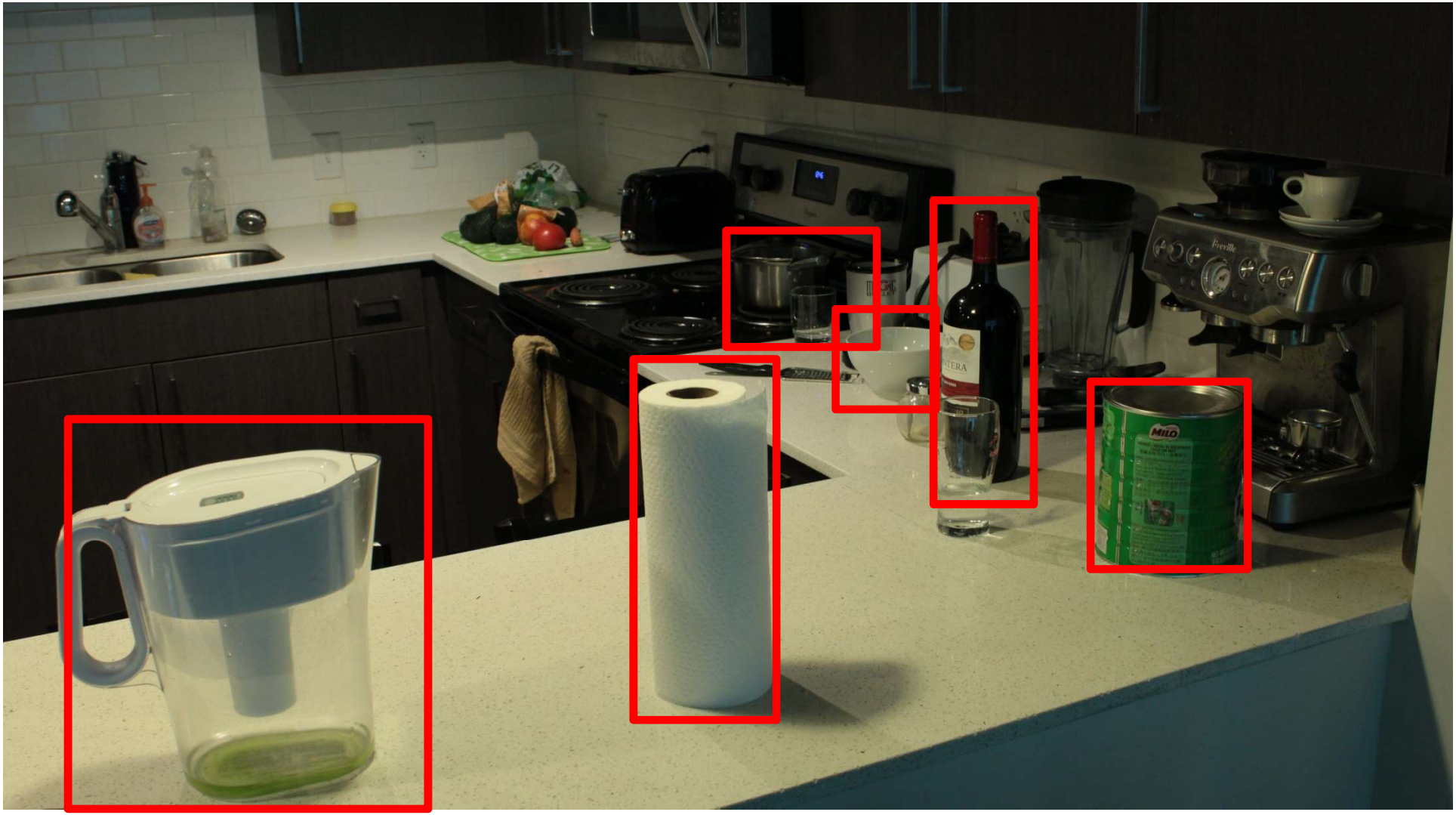
We have some soft objects ..

Let's take an example environment…



And some hard objects …

Let's take an example environment…

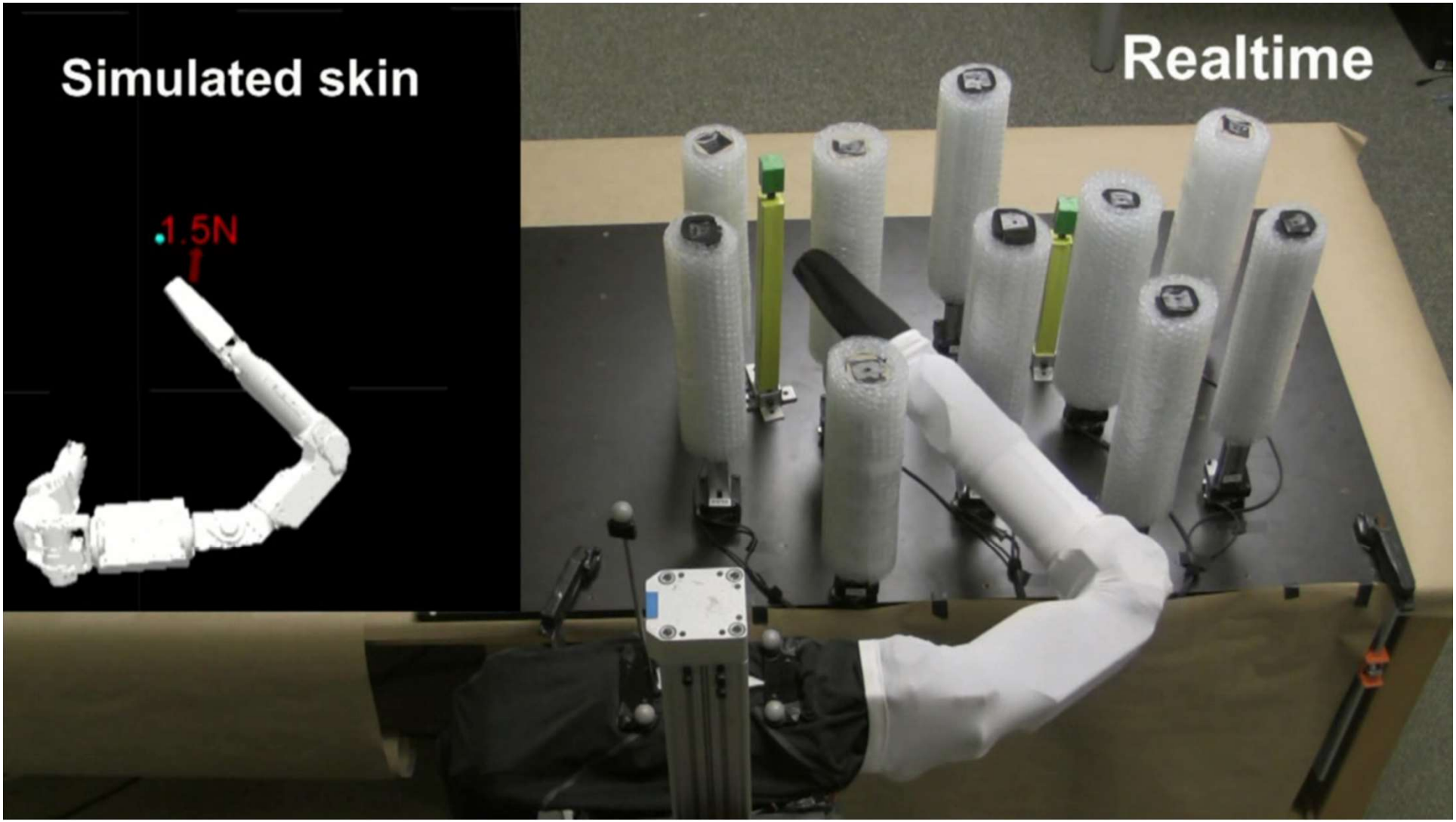


Also, during manipulation, objects can move

Can you perceive the properties using vision alone ?

What about the sense of touch?
Whole-arm tactile sensing!

Autonomous Reaching

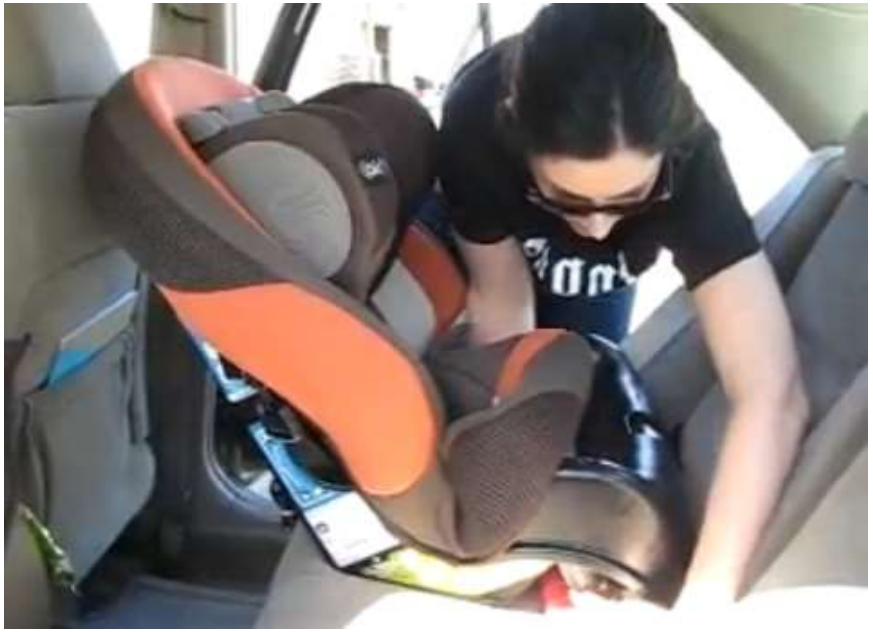


Advait Jain, Marc D. Killpack, Aaron Edsinger, and Charles C. Kemp, *Reaching in clutter with whole-arm tactile sensing*. The International Journal of Robotics Research, 2013.

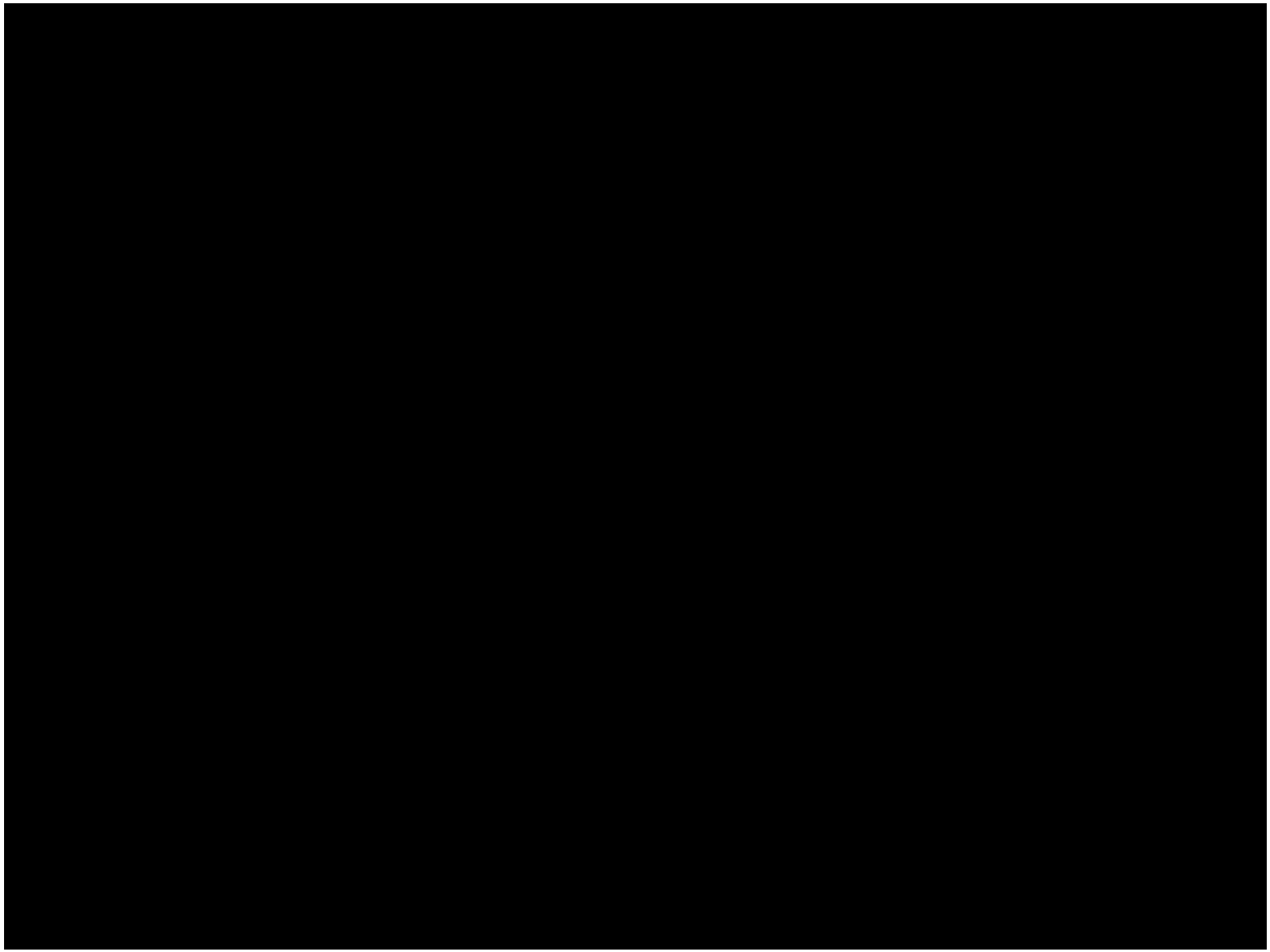
Assistive Scenarios

Phillip M. Grice, Marc D. Killpack, Advait Jain, Sarvagya Vaish, Jeffrey Hawke, and Charles C. Kemp, *Whole-arm Tactile Sensing for Beneficial and Acceptable Contact During Robotic Assistance*, 13th International Conference on Rehabilitation Robotics (ICORR), 2013.

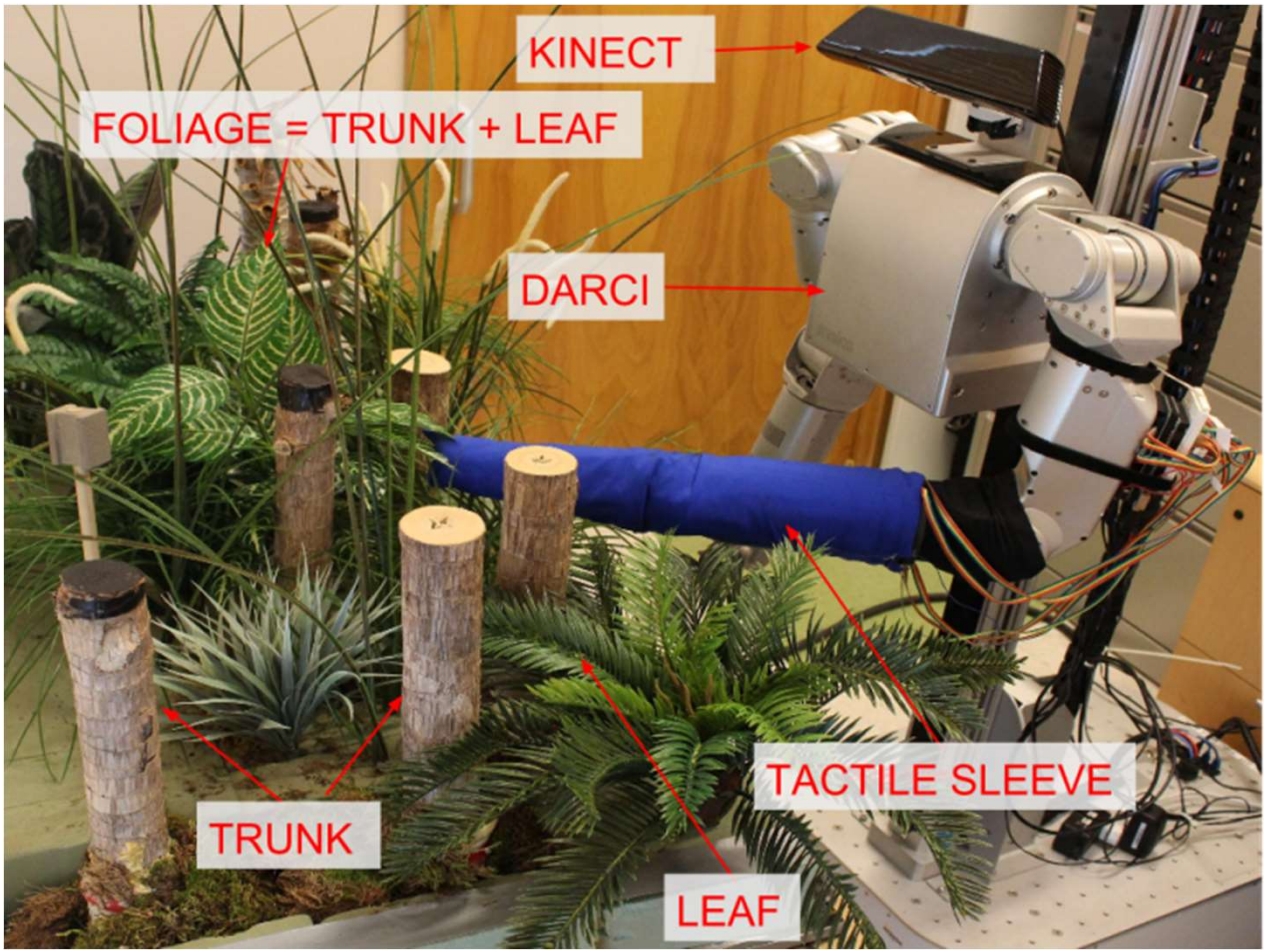
Some examples of Contact



An artificial capacitive-sensing skin

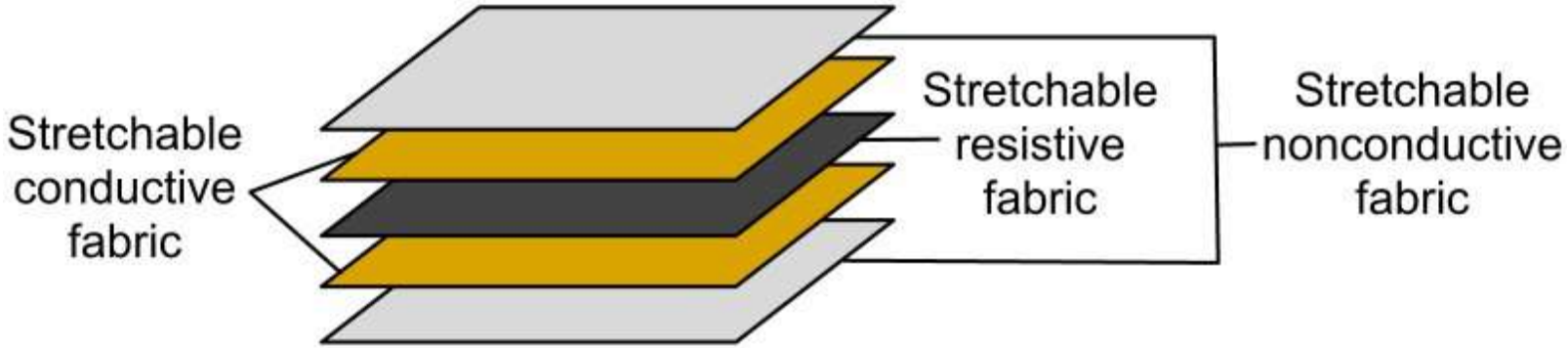


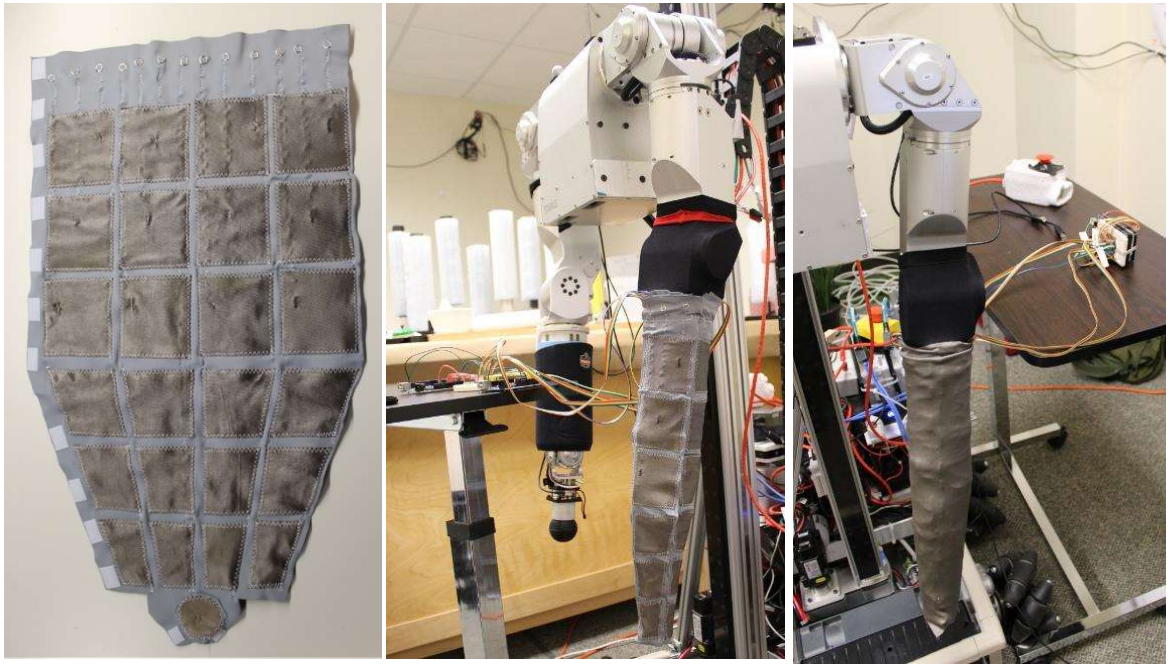
But, how to cover joints?



Stretchable Fabric-based Resistive Sleeve!

Stretchable Fabric Tactile Sensors

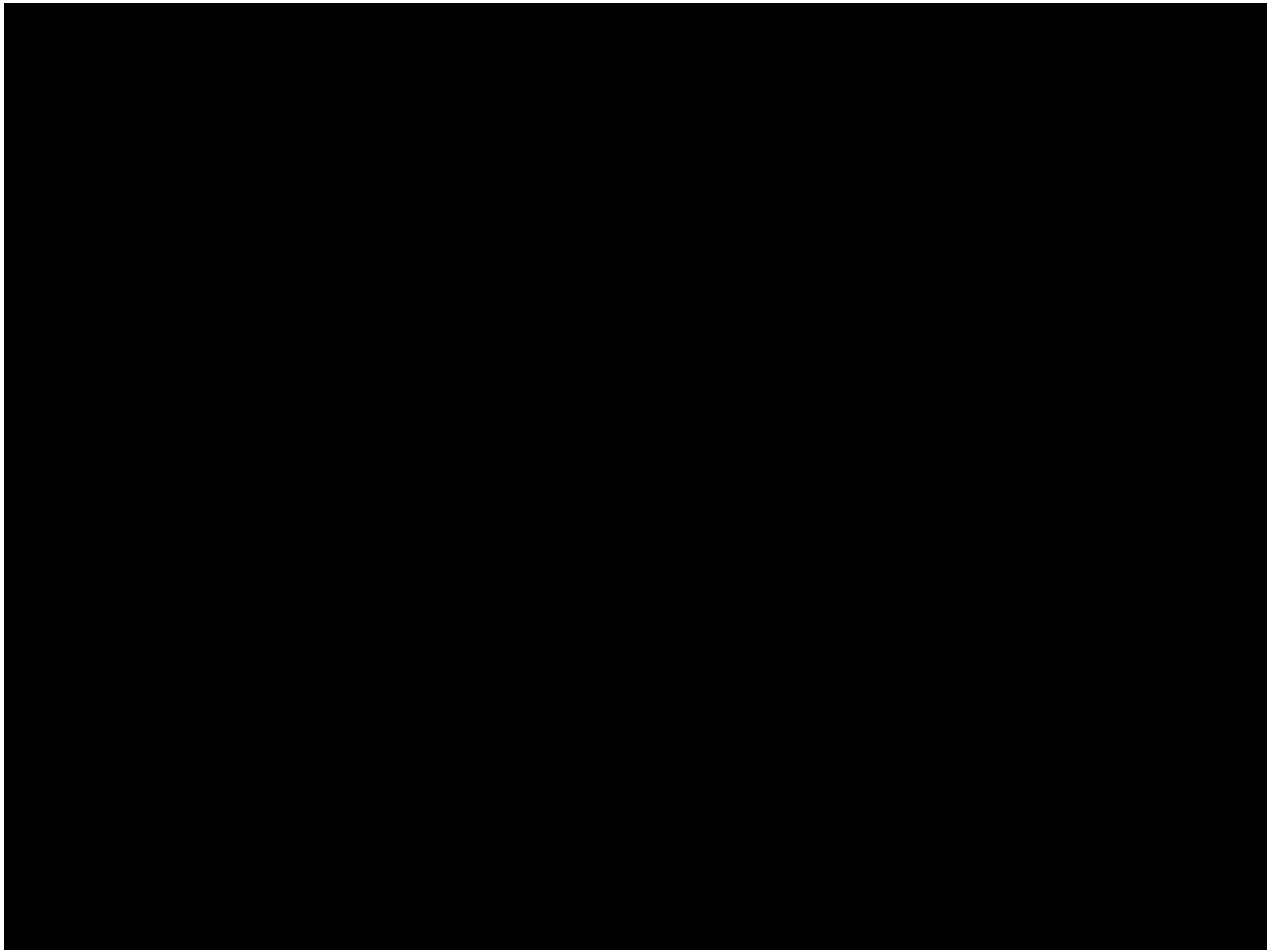




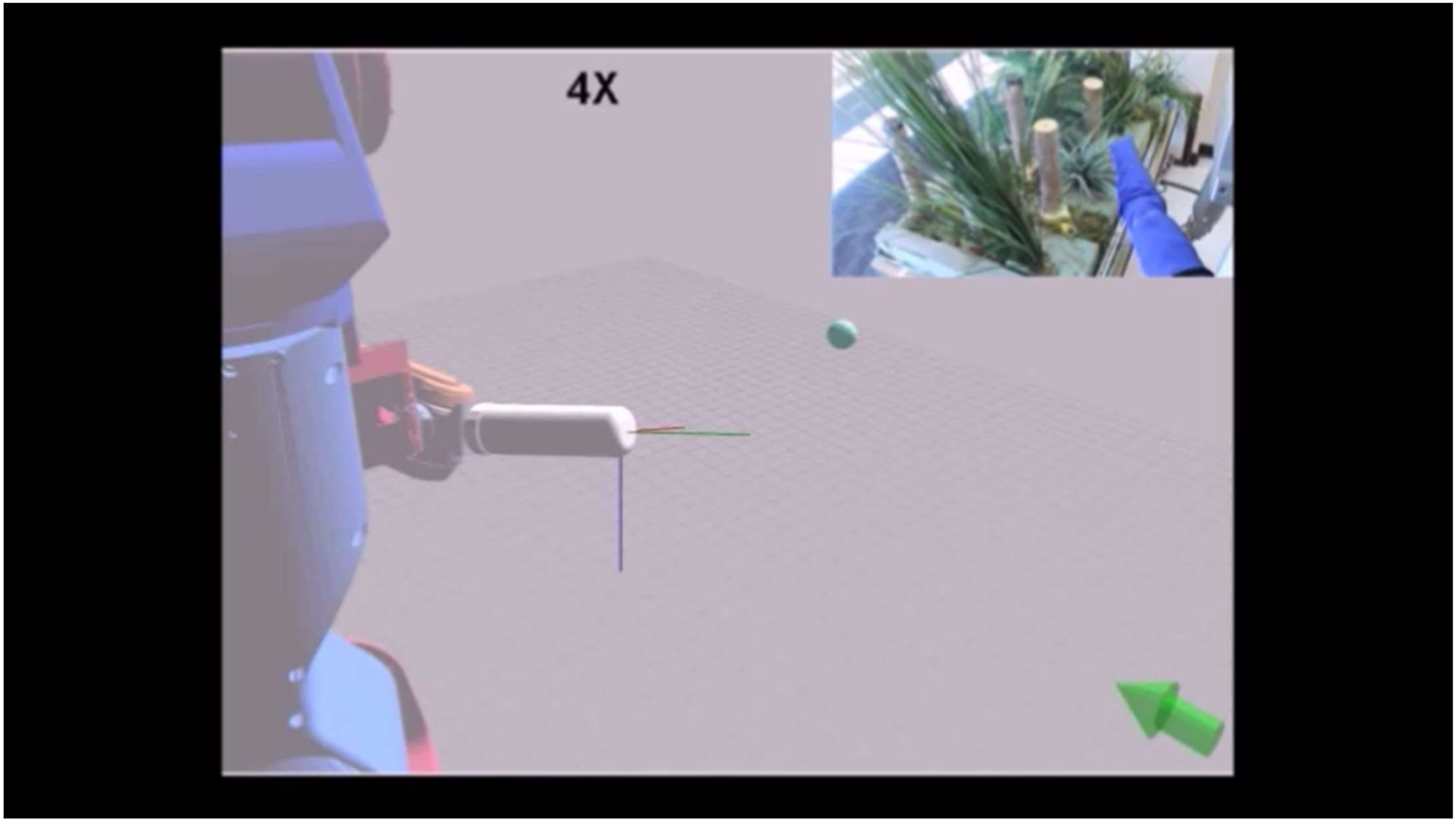
- **25 discrete tactile sensor elements (taxels)**
  - 12 on forearm
  - 13 on the gripper
- **Open hardware**

Tapomayukh Bhattacharjee, Advait Jain, Sarvagya Vaish, Marc D. Killpack, and Charles C. Kemp, Tactile Sensing over Articulated Joints with Stretchable Sensors, IEEE World Haptics Conference (WHC 2013), 2013

Rapid Haptic Mapping : Force



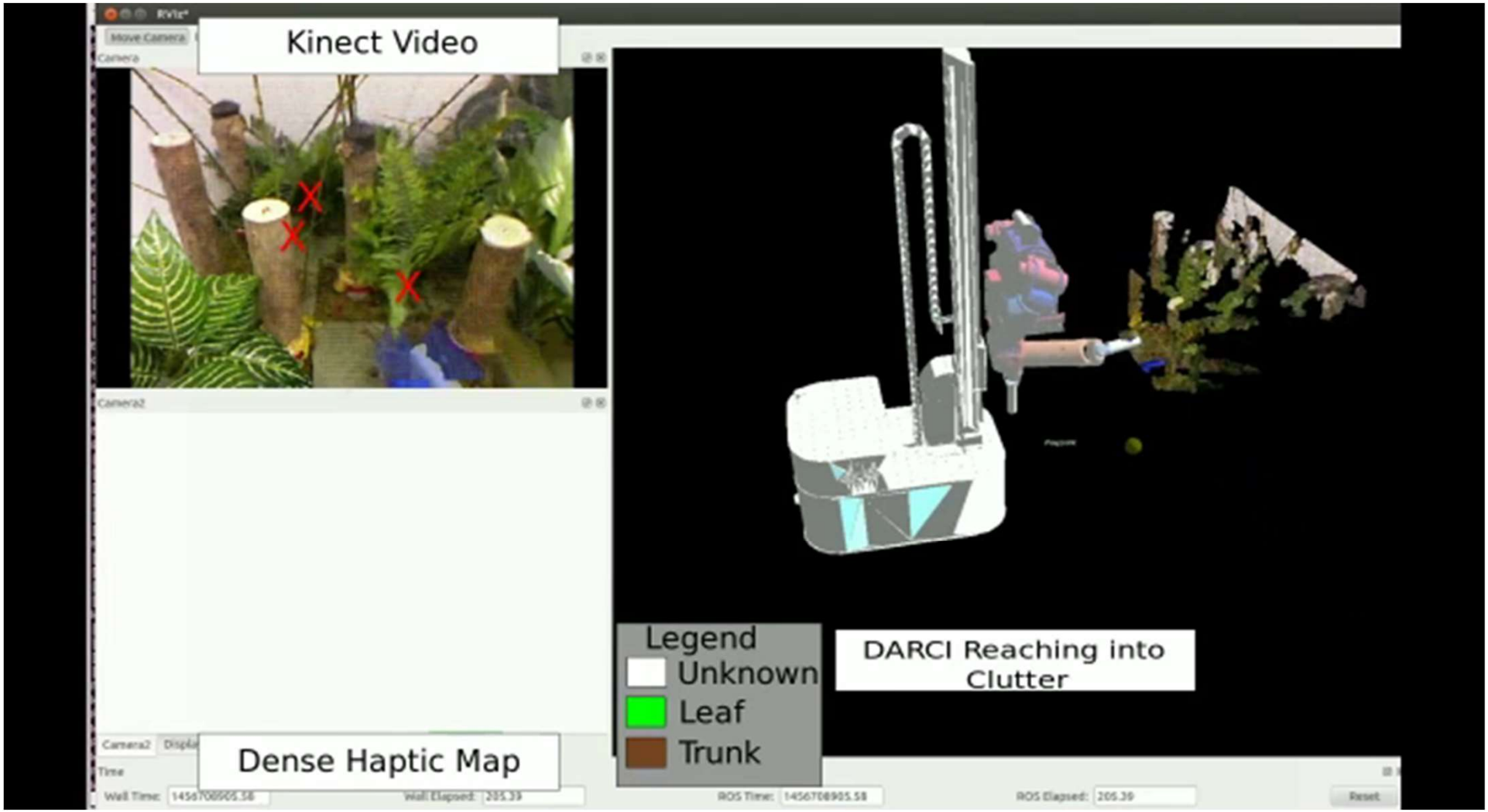
Rapid Haptic Mapping : Force + Vision



Dense Haptic map used for planning, one try

Tapomayukh Bhattacharjee, Ashwin A. Shenoi, Daehyung Park, James M. Rehg, and Charles C. Kemp, *Combining Tactile Sensing and Vision for Rapid Haptic Mapping*, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2015.

Rapid Haptic Mapping : Force + Vision

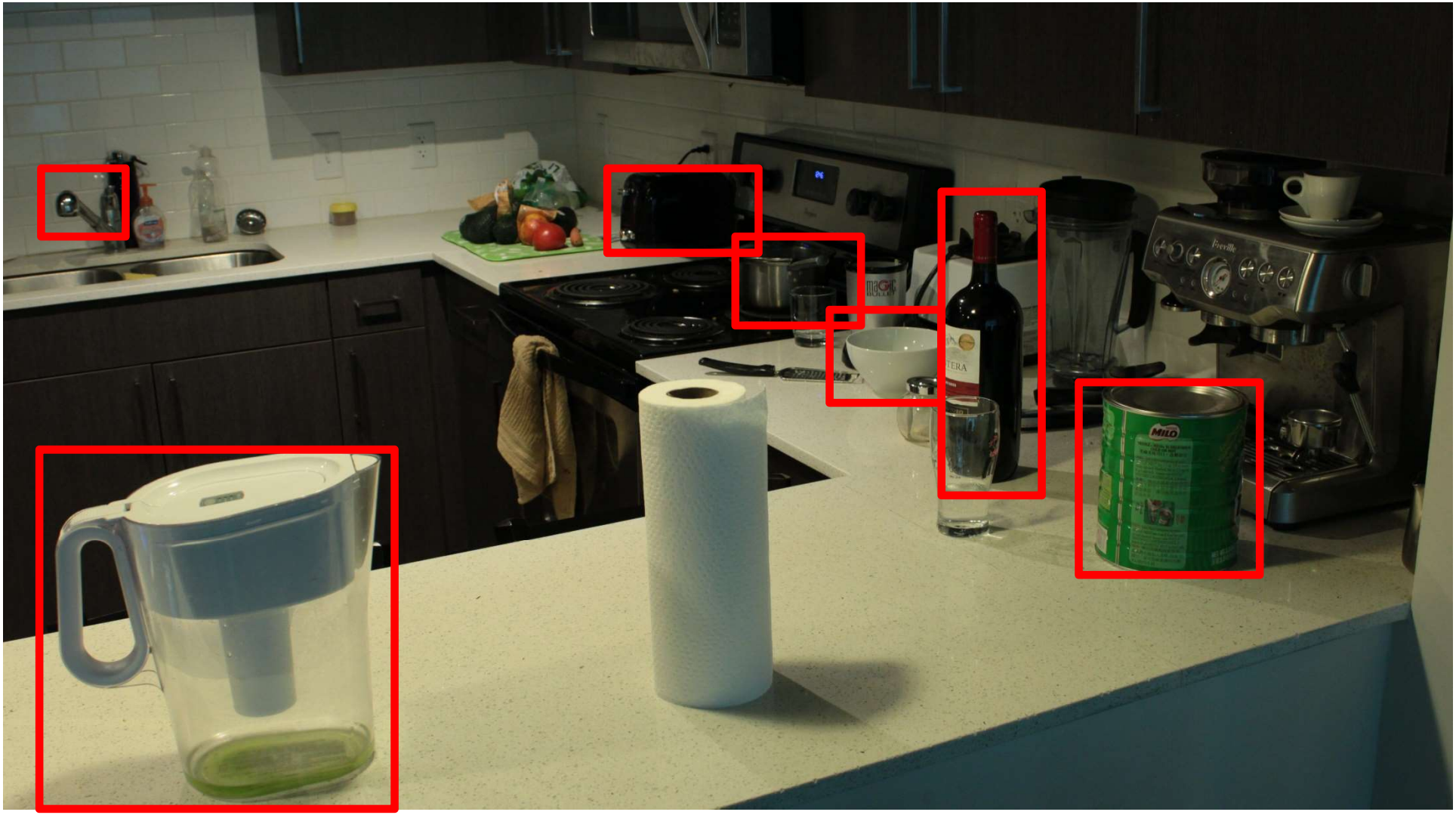


Dense Haptic map

Let's revisit example environment…

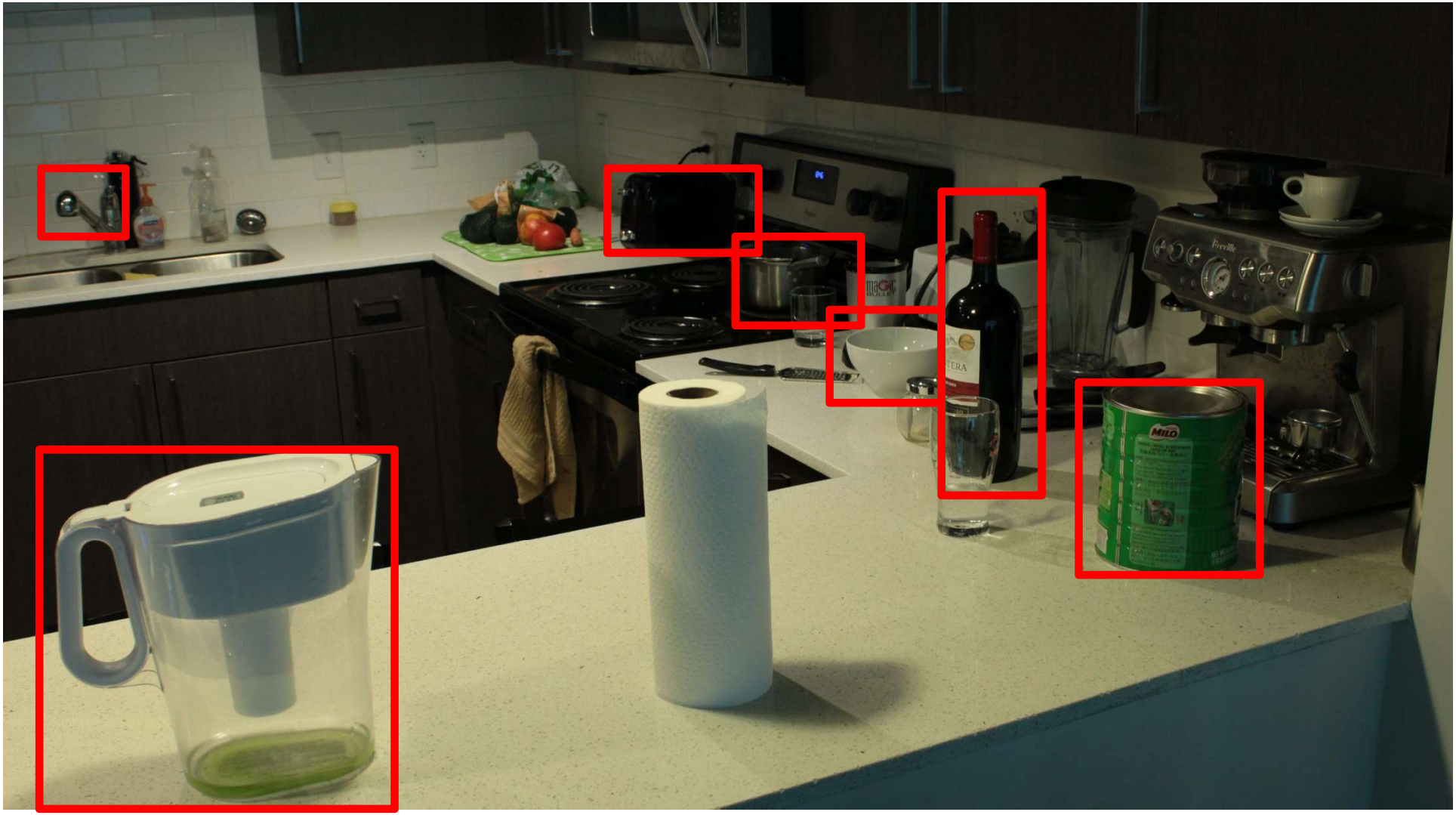
A Kitchen

Let's revisit example environment…



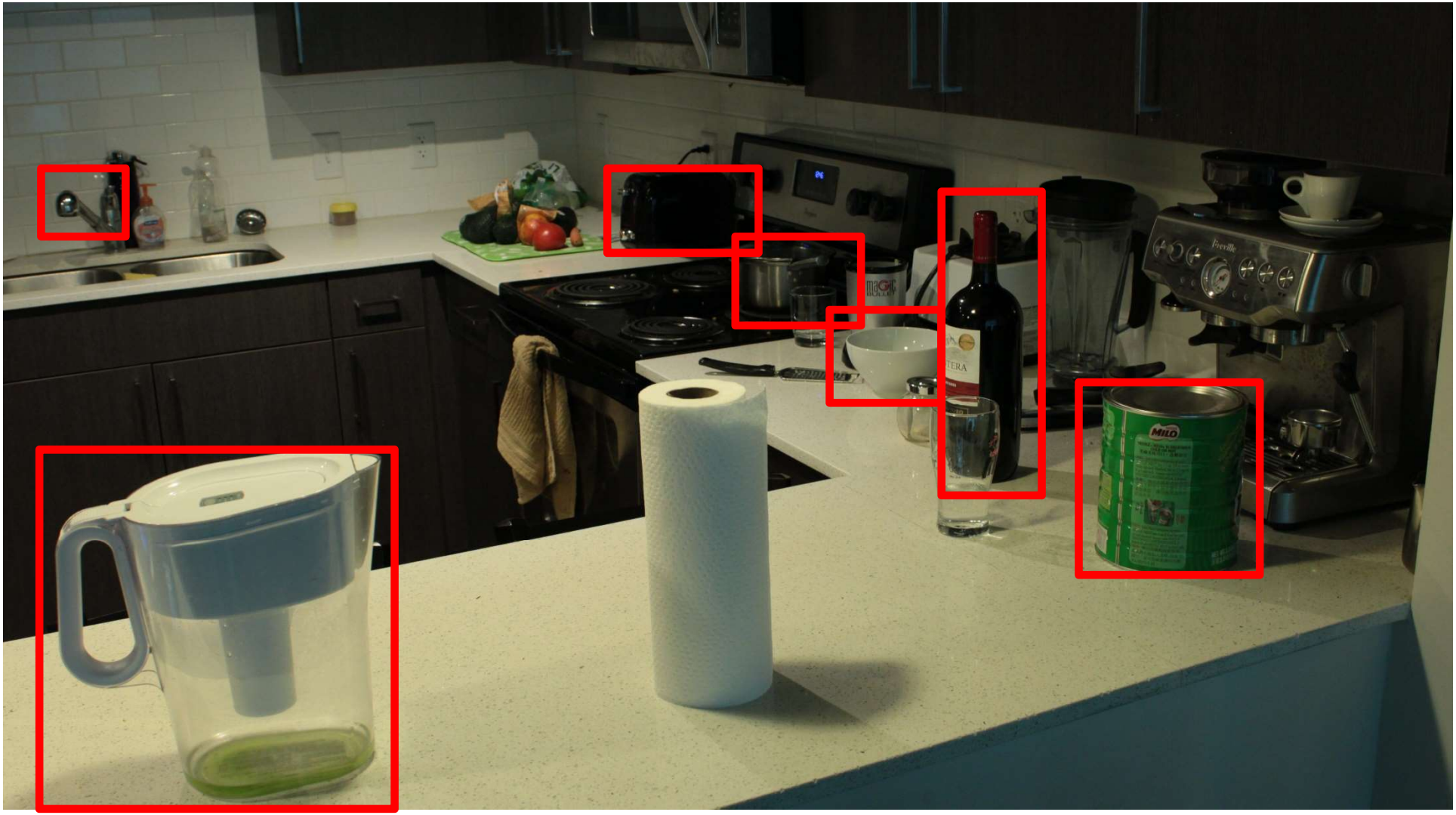
We have some hard objects …

Let's revisit example environment…



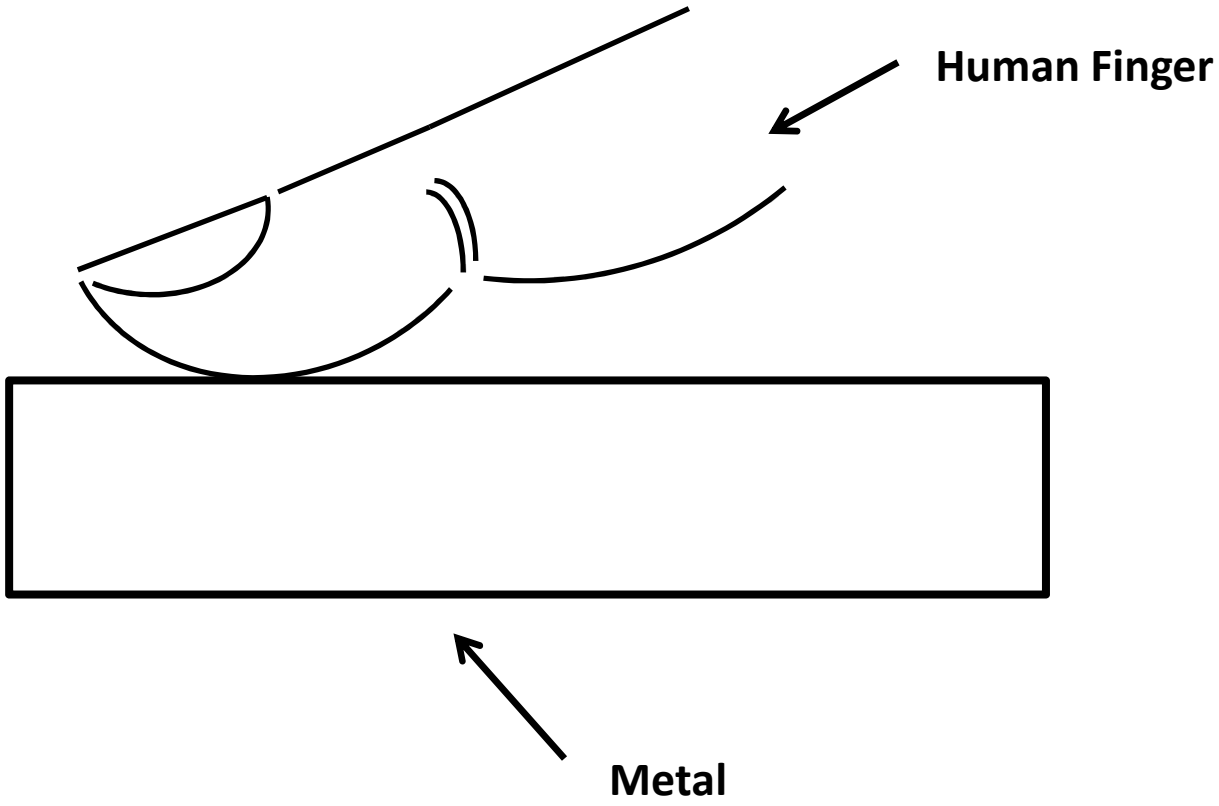
But, can a robot distinguish material properties of the hard objects using force sensing ?

Let's revisit example environment…

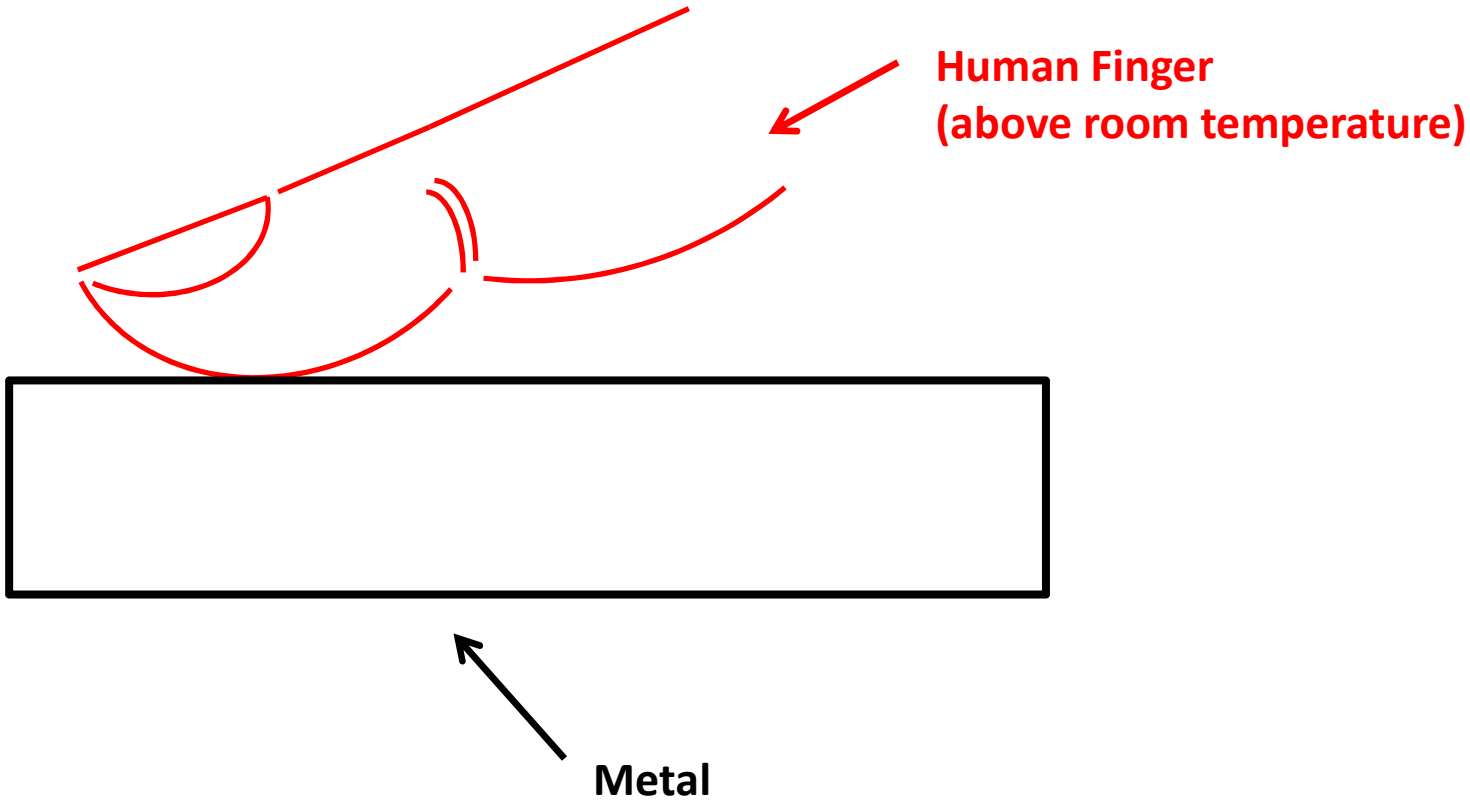


They may have different thermal properties ! What can we do with thermal sensing ?

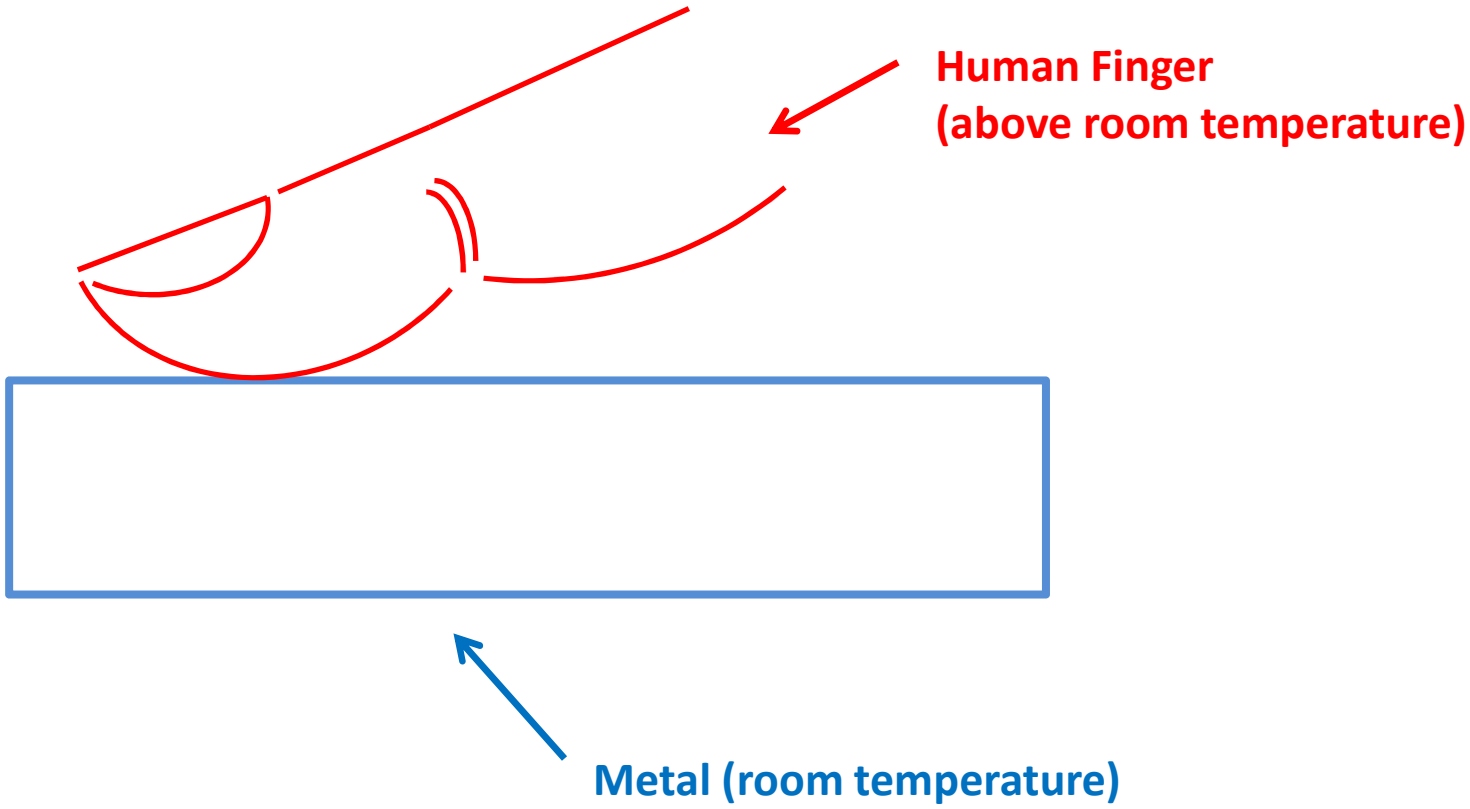
Active Thermal Sensing



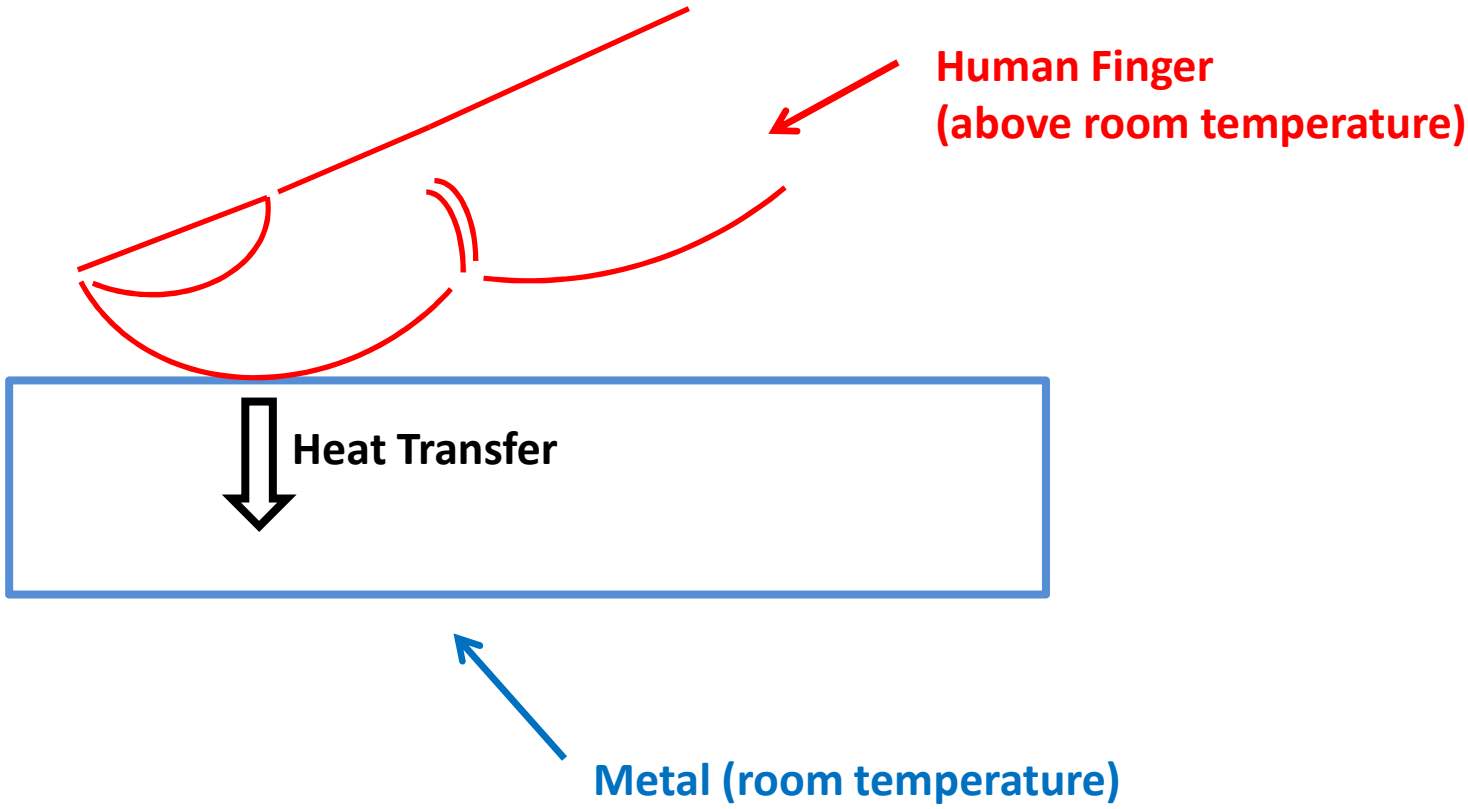
Active Thermal Sensing



Active Thermal Sensing



Active Thermal Sensing

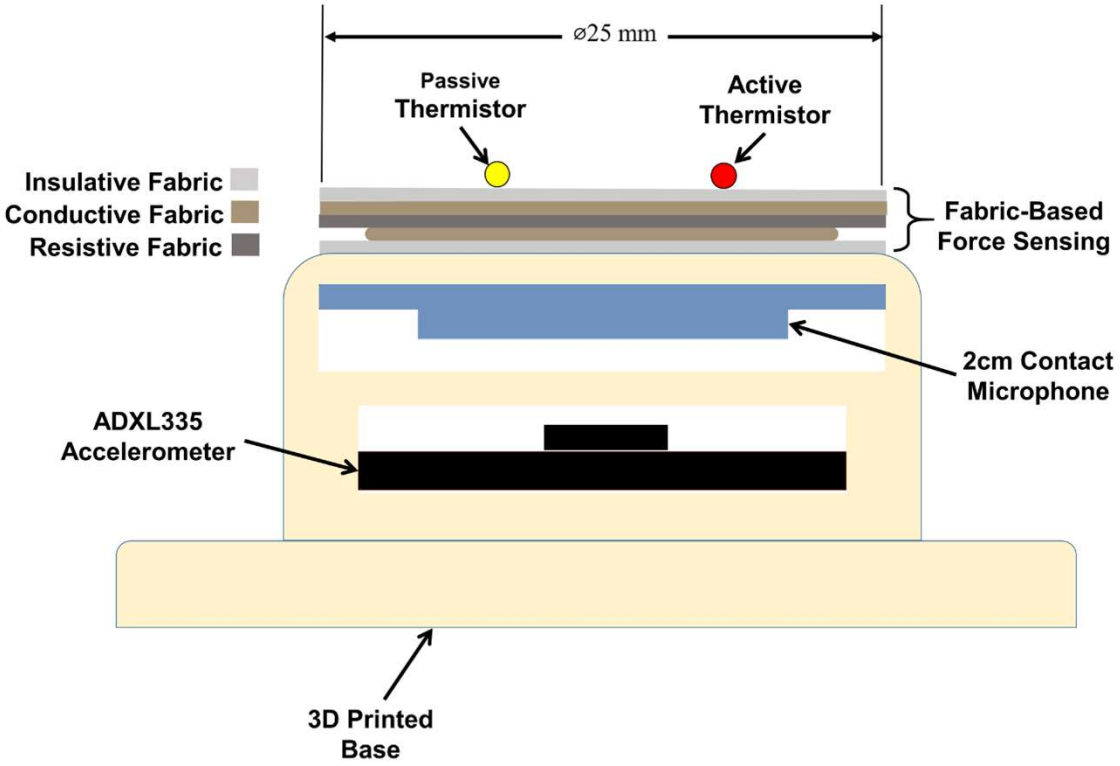


Passive thermal sensing

A simple 1-DOF device as a testbed

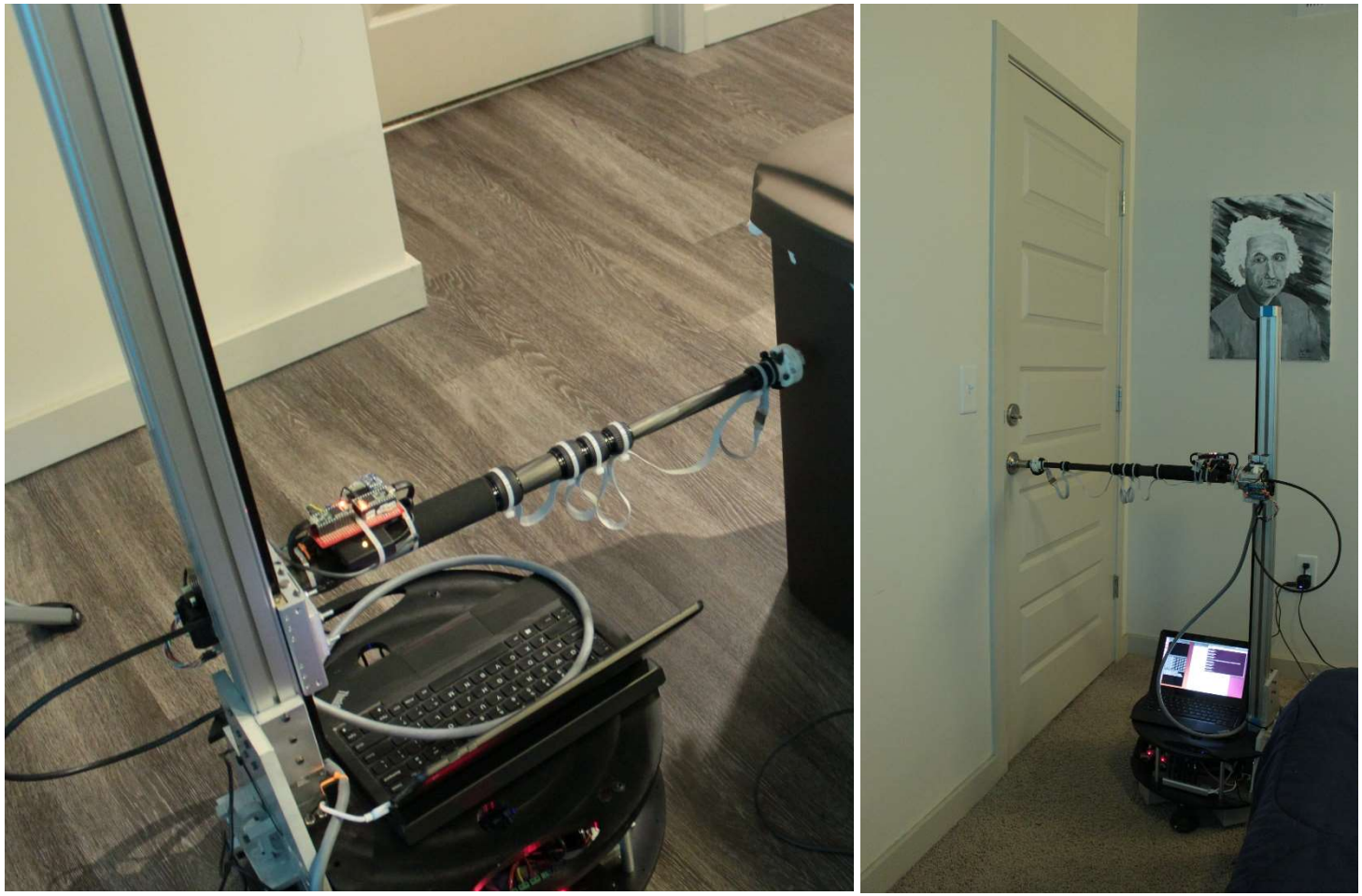
What if we combine force and thermal ?

A Multimodal Sensing Module …



Tapomayukh Bhattacharjee, Joshua Wade, Henry M. Clever, and Charles C. Kemp, *Generalizing In-Situ Multimodal Haptic Perception Performance during Rapid First Contact,* in preparation, 2017.

… attached to a Linear Actuator on a Mobile Robot…

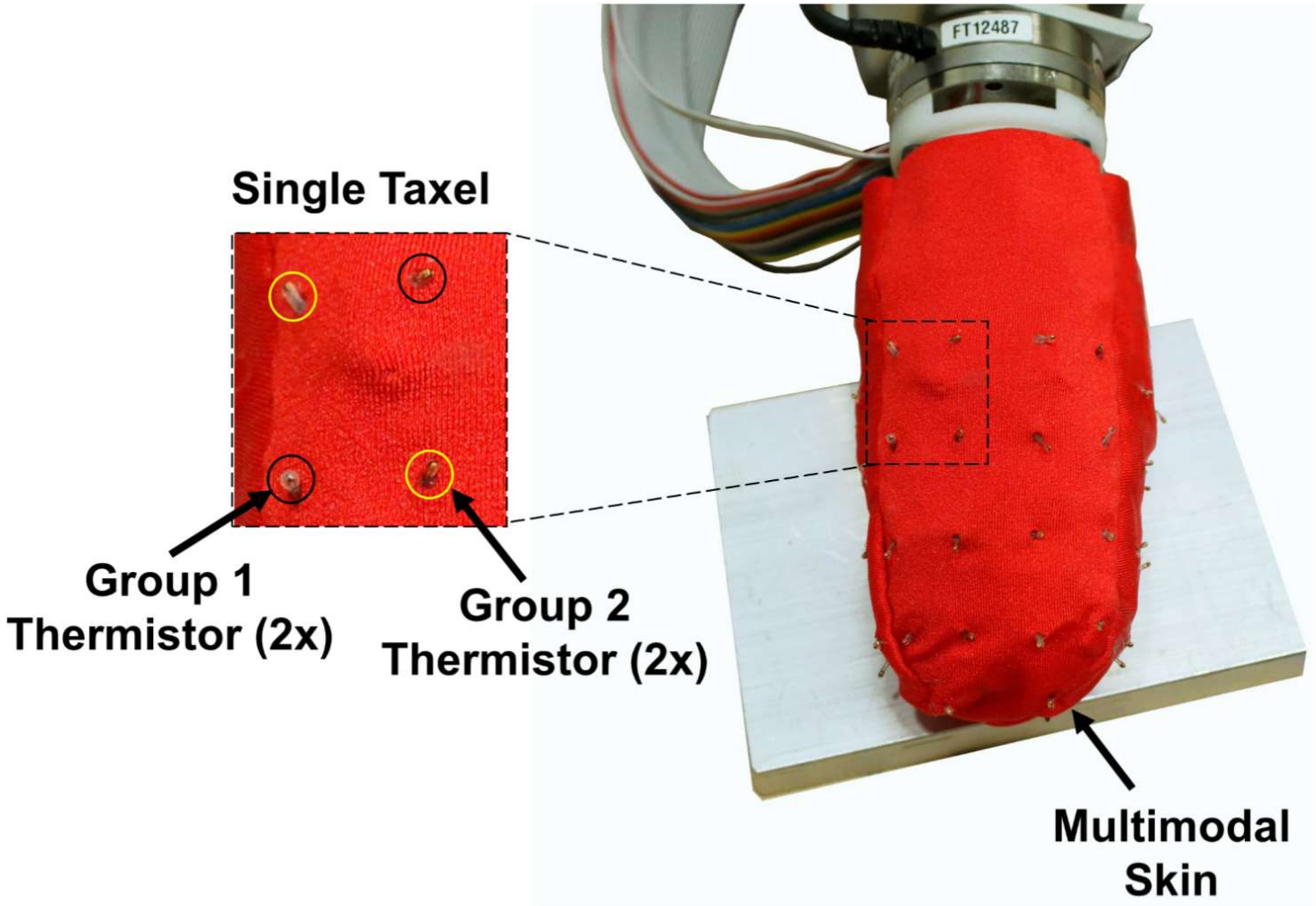


Tapomayukh Bhattacharjee, Joshua Wade, Henry M. Clever, and Charles C. Kemp, *Generalizing In-Situ Multimodal Haptic Perception Performance during Rapid First Contact,* in preparation, 2017.

… perceived objects in a real home!

A mobile robot with a multimodal sensor
touching various objects ...

Force and Thermal Sensing with a Fabric-Based Skin



Joshua Wade, **Tapomayukh Bhattacharjee**, Ryan D. Williams, and Charles C. Kemp, *A Force and Thermal Sensing Skin for Robots in Human Environments,* Under Review, 2017.

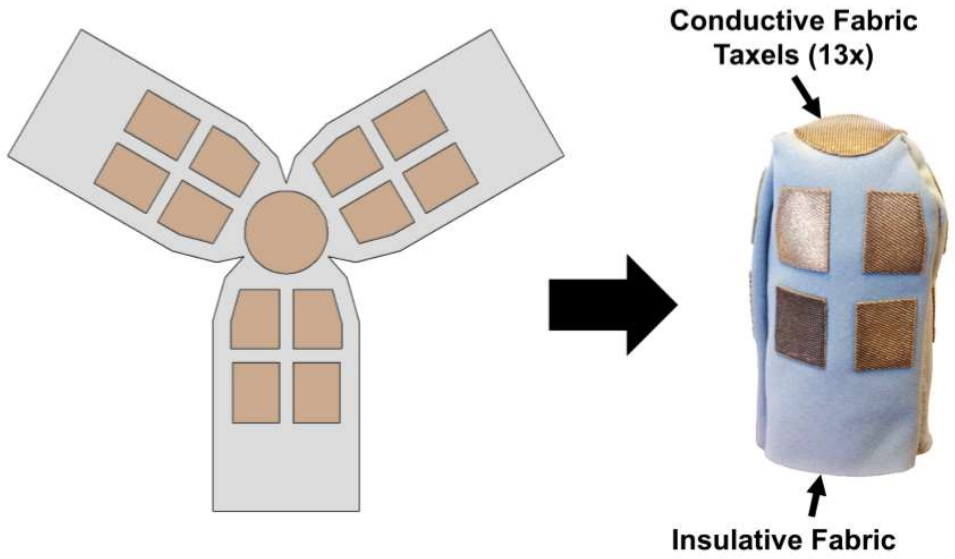


Figure 2: *Arrangement of force sensing taxels on our multimodal skin prototype.*

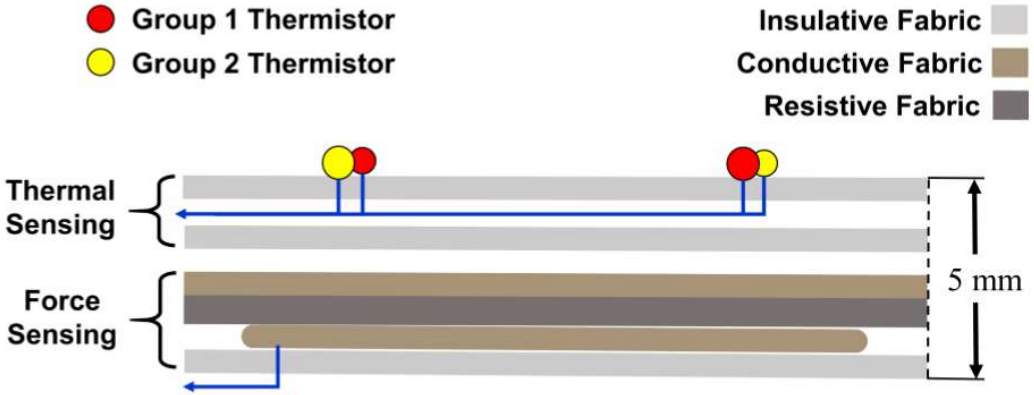
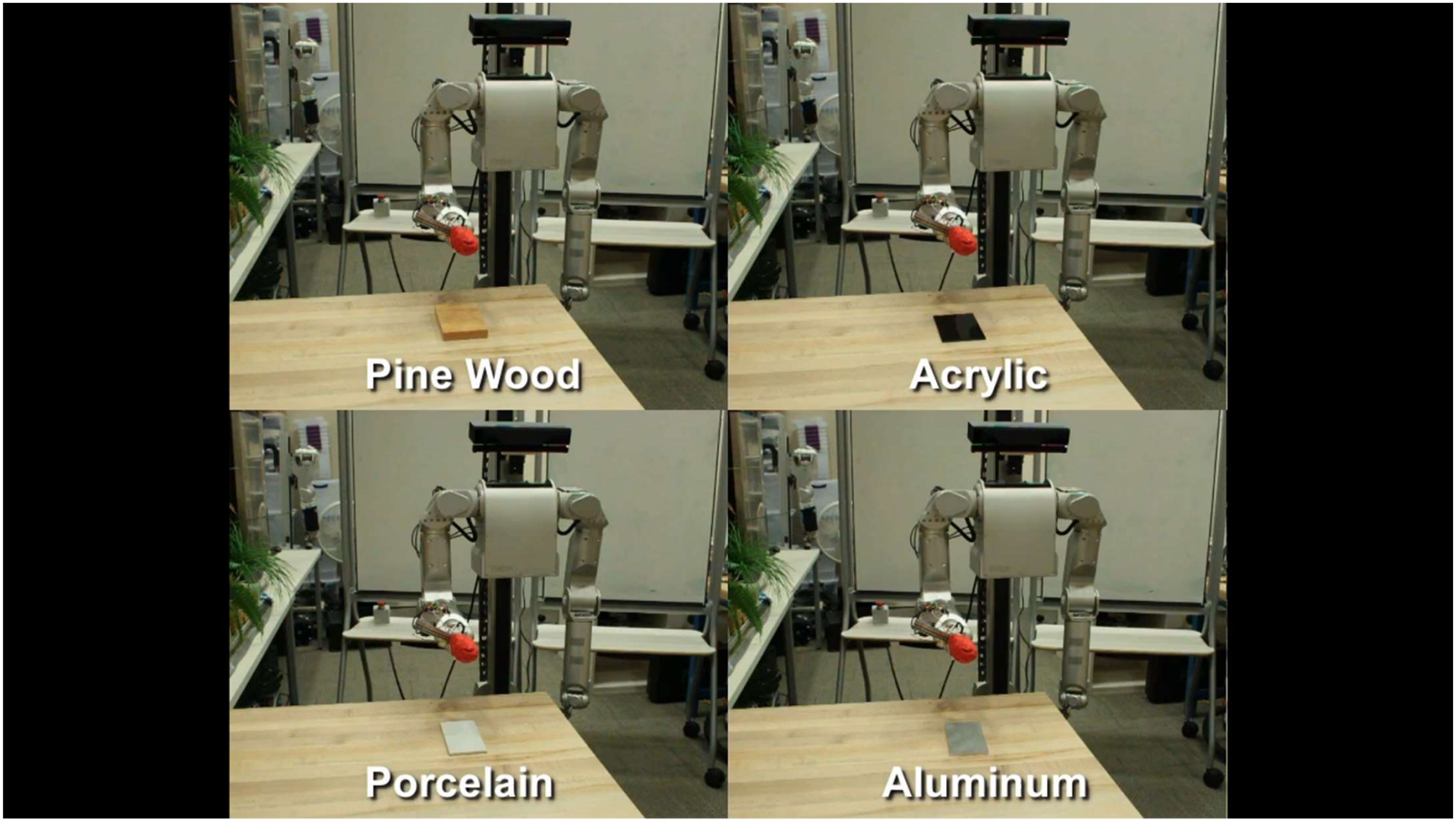
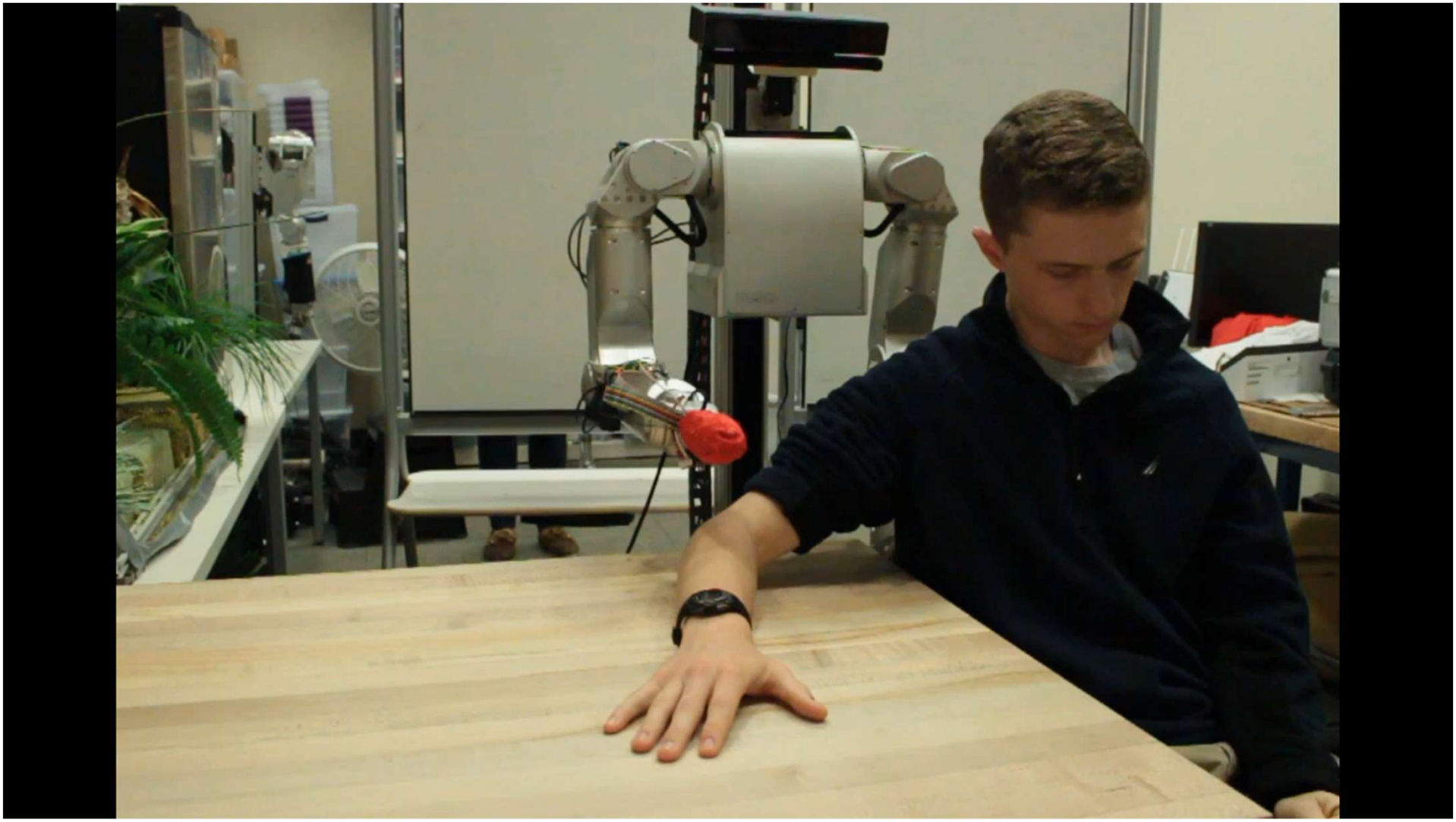


Figure 3: *Multimodal taxel design.*

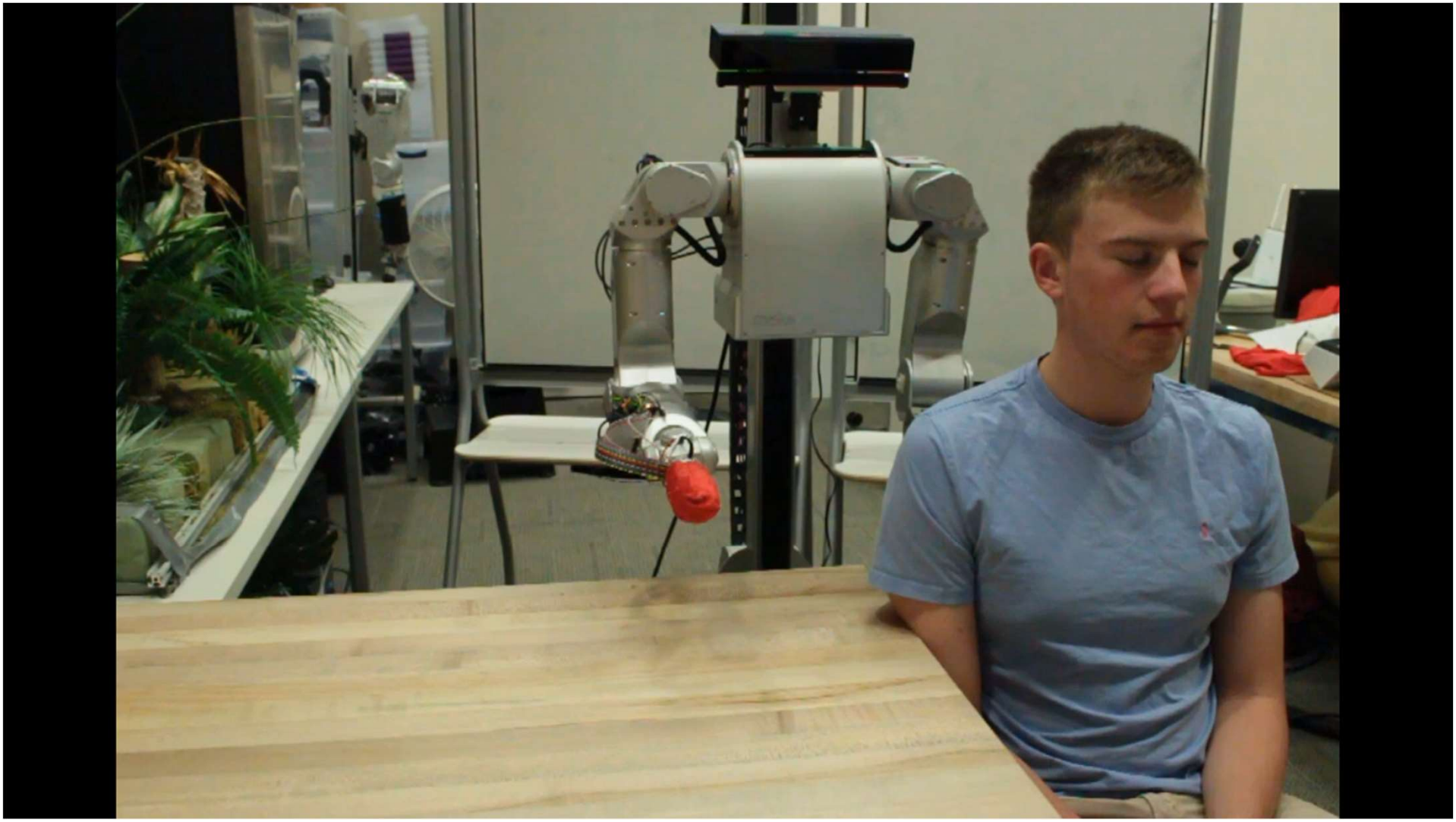
Contact with Materials



Contact with Human Body : Bare Forearm



Contact with Human Body : Clothed Shoulder



Take-Home Message

- Robotics is highly interdisciplinary
- Physical interaction with the world is hard for robots!

Questions ?

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