Robot Autonomy

# Lecture 13:
# Grasping Overview

Oliver Kroemer

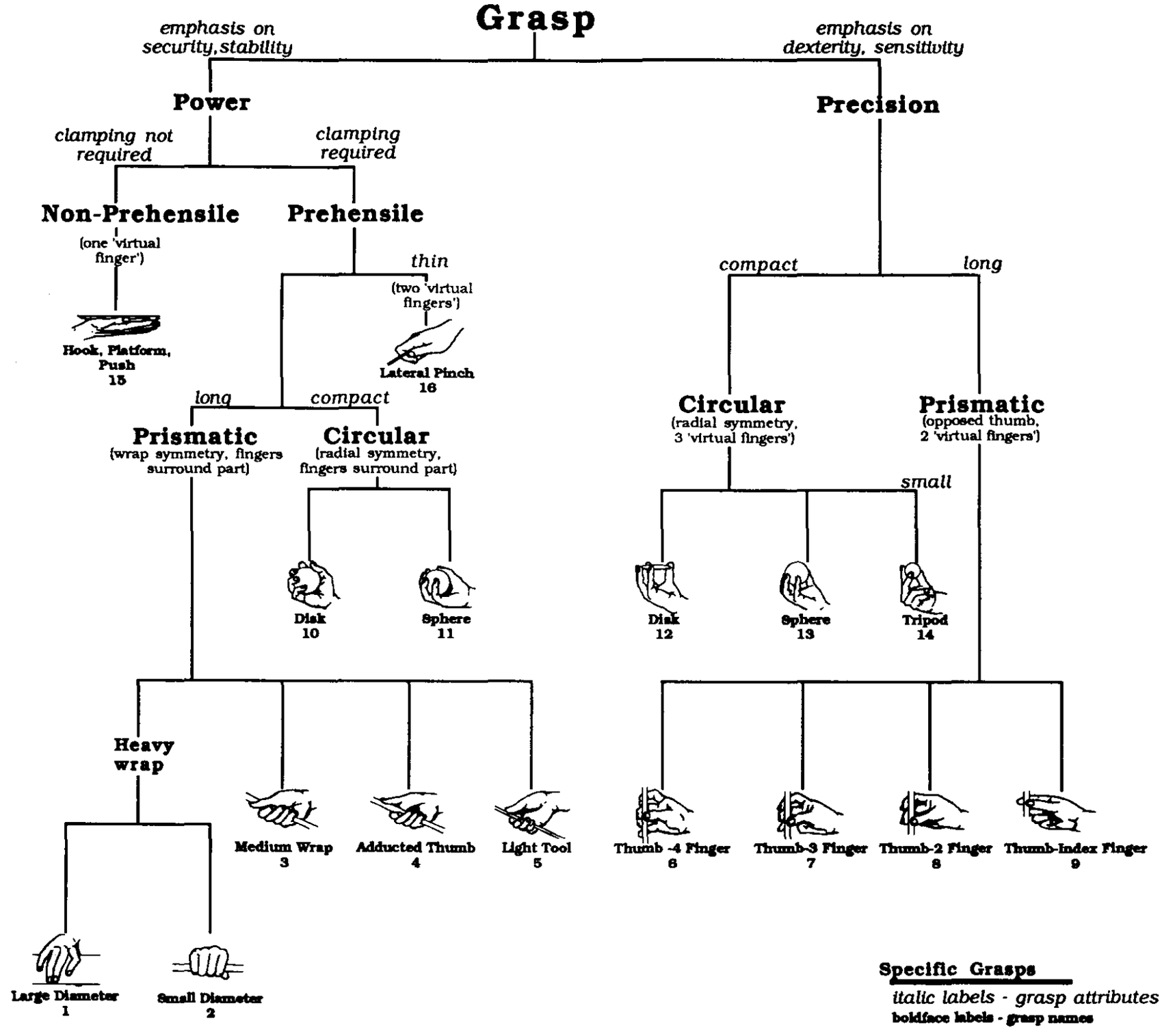
# Motivation

- Grasping is a fundamental skill for manipulating objects
  - Apply forces and move around grasped object
  - Basis for performing variety of other tasks



- Grasping is one example of a skill for switching modes
  - Create contacts between objects to achieve desired interaction
  - Other related skills include foot/tool/object placement
  - We will discuss modes and hybrid systems in a later lecture

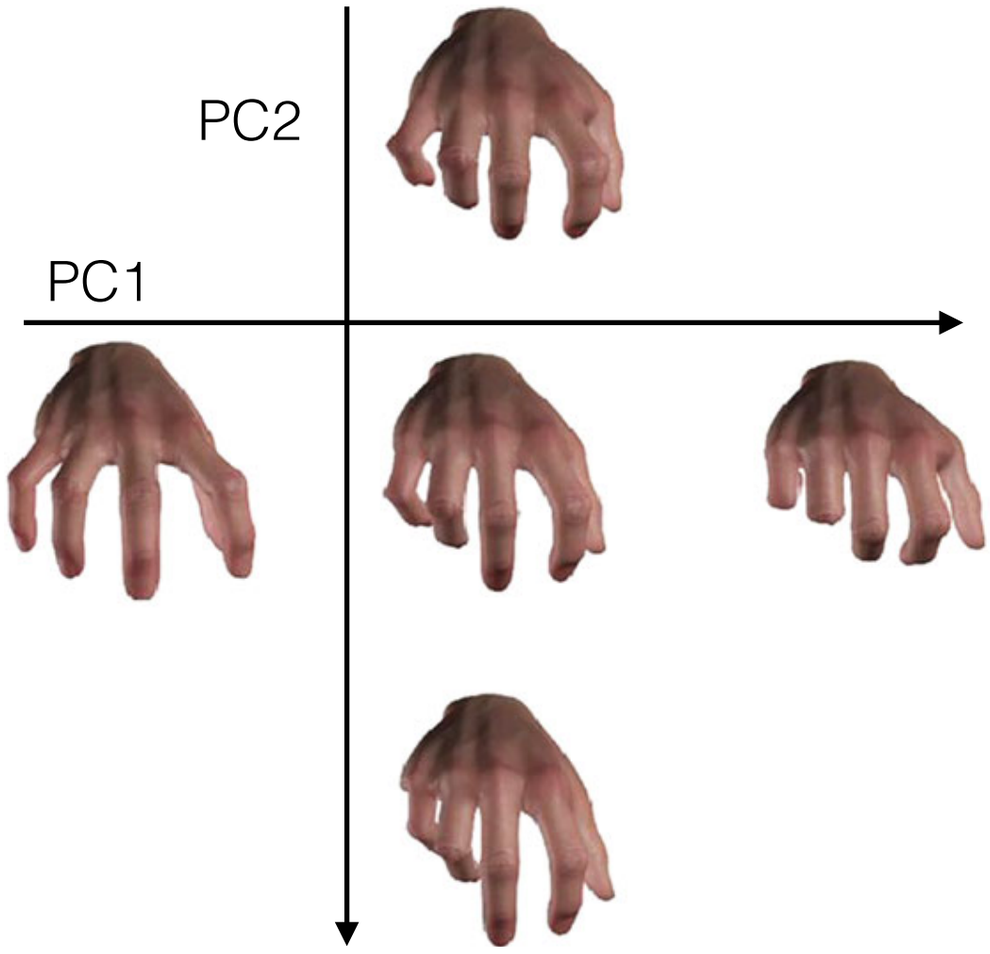
# Example Grasp Taxonomy

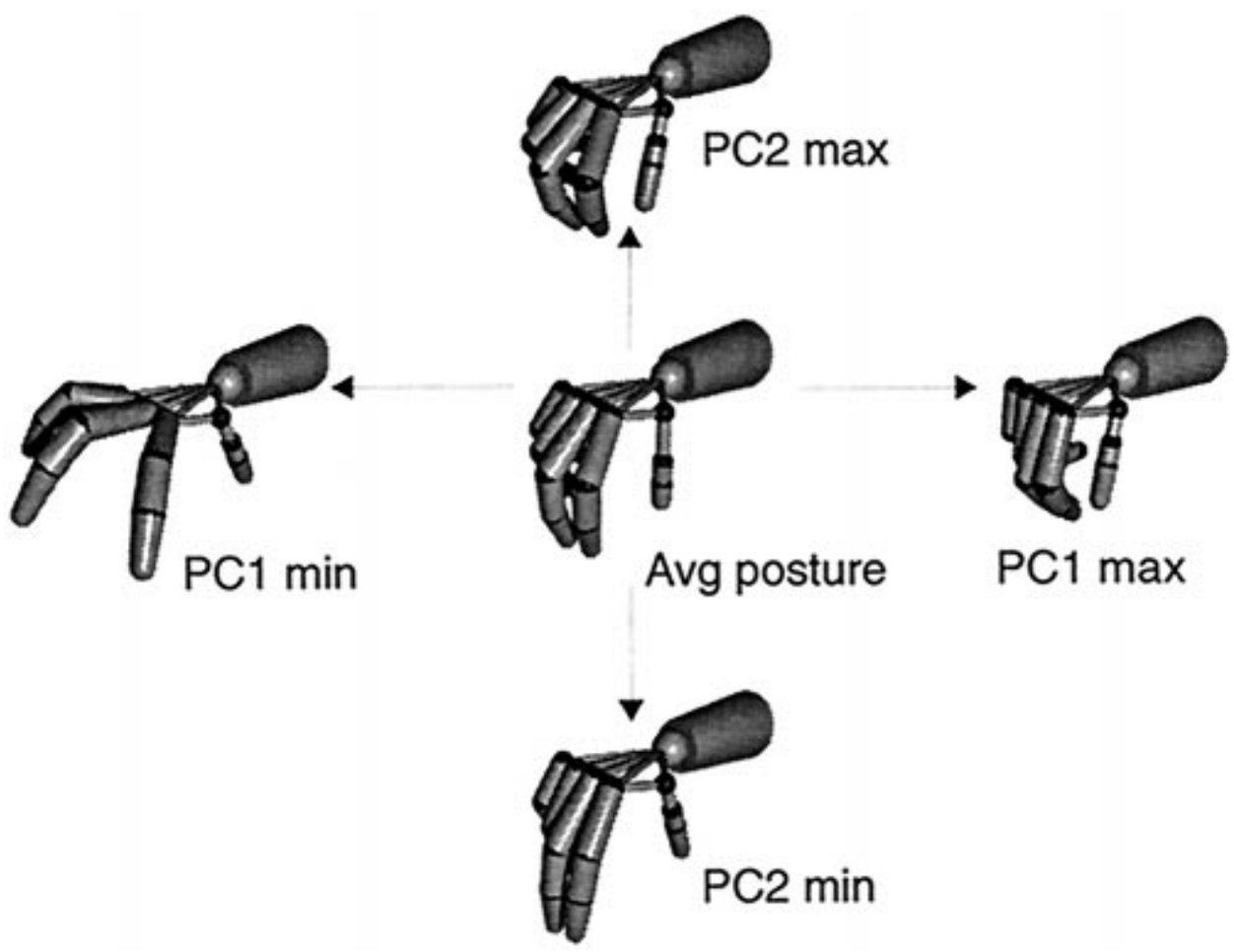



Mark Cutkosky; On Grasp Choice, Grasp Models, and the Design of Hands for Manufacturing Tasks, Transactions on Robotics and Automation 1989

# Postural Grasp Synergies

- Fingers are controlled in a coordinated manner




- First 2 principle components account for ~80% motion

Bicchi et al., Modelling Natural and Artificial Hands with Synergies, Philosophical Transactions 2011

Santello et al., Postural Hand synergies for Tool Use, Journal of Neuroscience, 1998

# Postural Grasp Synergies

- Principle Component Analysis of grasping hand shapes
  - Collect n example grasps with d finger joint angles for each

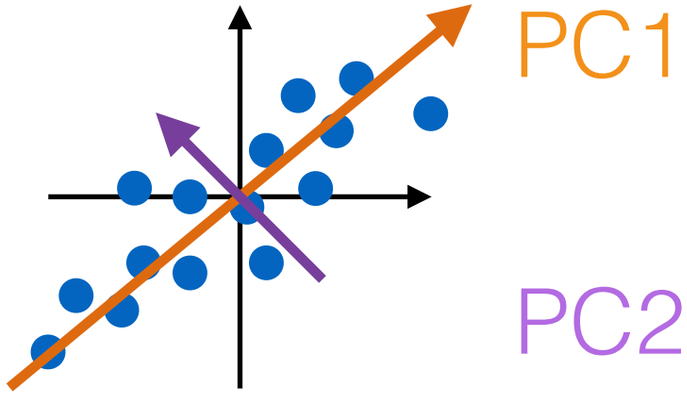
$$X = \begin{bmatrix} | & | & | & | \\ x_1 & x_2 & \dots & x_n \\ | & | & | & | \end{bmatrix}, x_i \in \mathbb{R}^d$$

zero-mean rows

  - Compute eigenvectors and eigenvalues of covariance matrix

$$\text{eig}(n^{-1} X X^T)$$

  - Use eigenvectors with the k largest eigenvalues (k<d)




  - Selects k dimensions that minimize squared reconstruction error

# Synergies and Object Interactions

- The Softhand mimics only the first grasp synergy

Antonio Bicchi, Pisa/IIT Softhand, YouTube 2014

# Precision and Power Grasps

- Power grasps
  Tend to employ the palm of the hand and rely on the arm to subsequently move the object.



- Precision grasps
  Use the pads of the fingers more and, hence, allow for more precise handling with finger movements

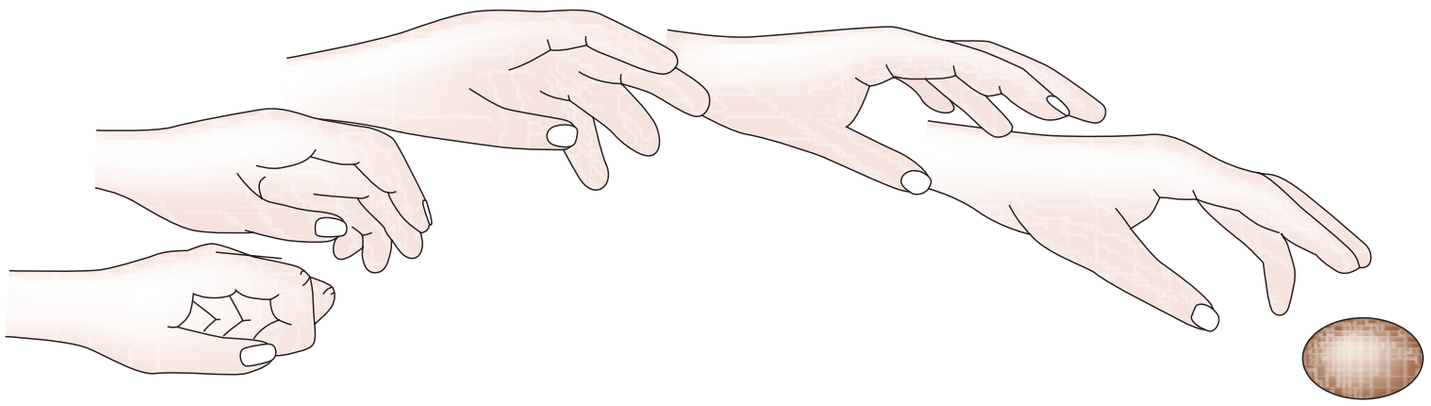


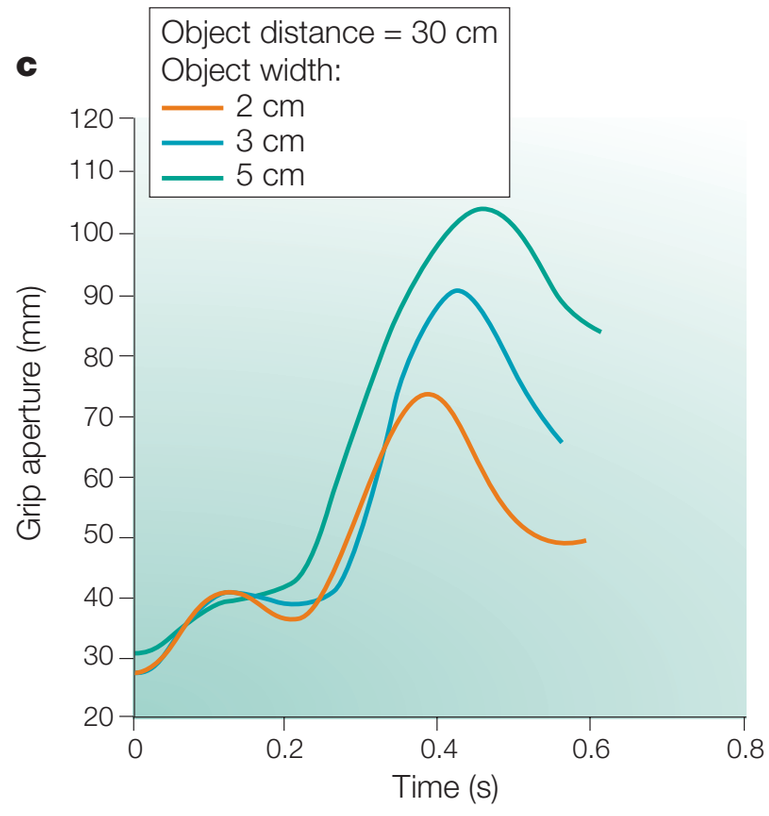
- Intermediate grasps - include properties of both

For a more detailed taxonomy see:
Feix et al., the GRASP Taxonomy of Human Grasp Types, Transactions on Human Machine Systems 2016
Liu et al., A Taxonomy of Everyday Grasps in Action, Humanoids 2014

# Reaching to Grasp

- Infants have a basic grasping reflex based on contact
- Learn to adapt grasping motions to objects

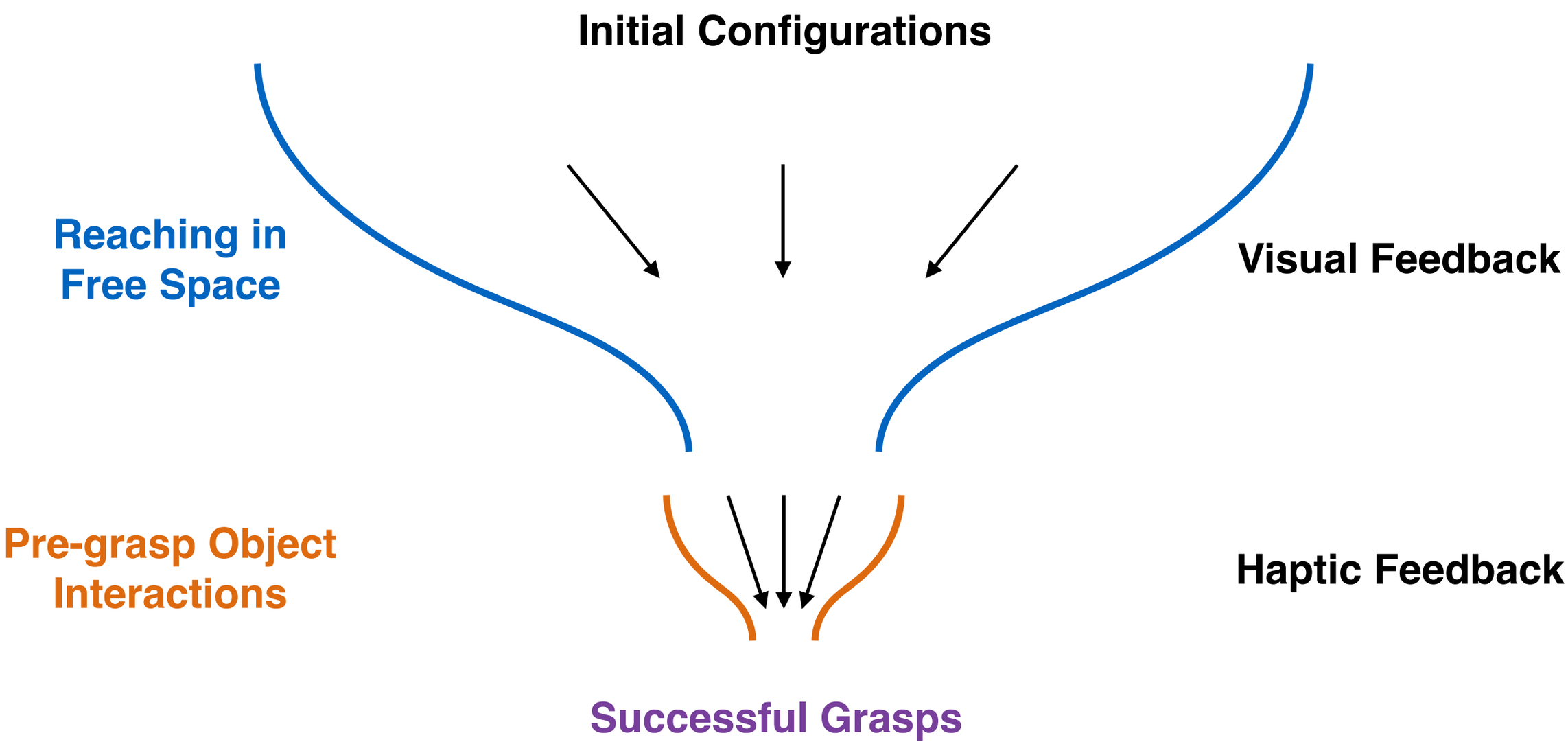





- Grip aperture largest at around 60-70% of movement
- Max aperture depends on object size and other properties

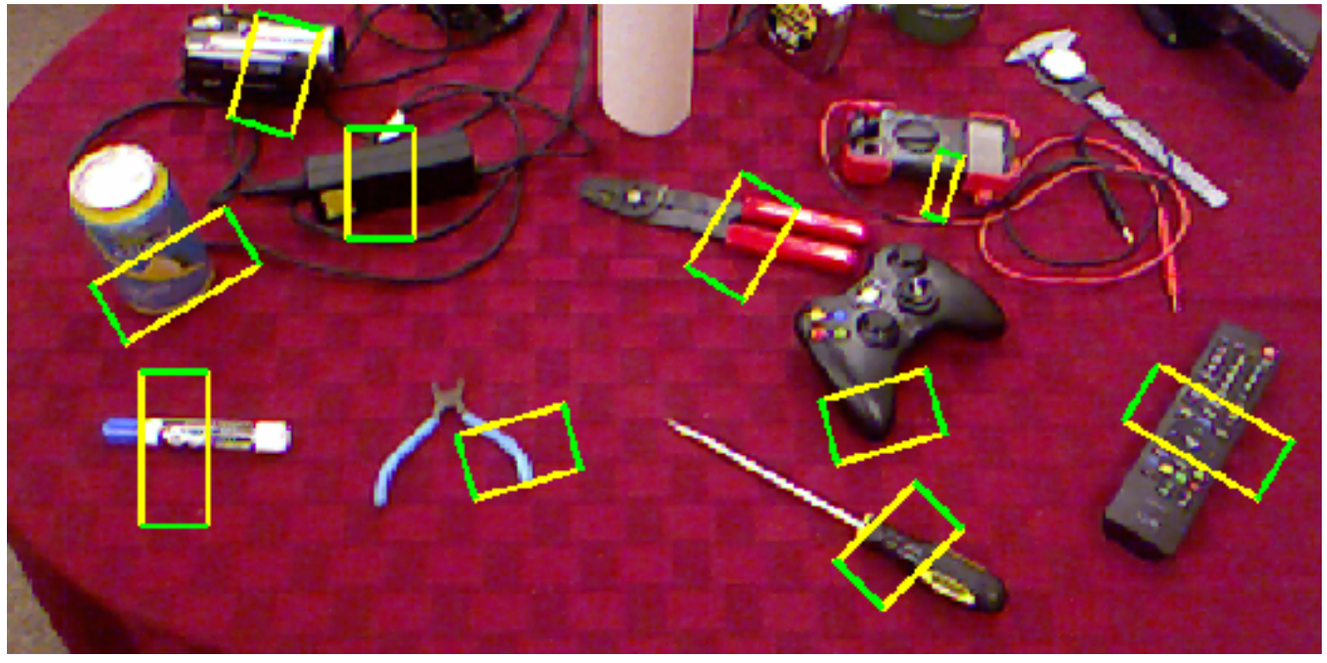
Umberto Castiello; Neurosciene of Grasping, Nature Reviews Science 2005
M. Jeannerod; Intersegmental Coordination During Reaching at Natural Visual Objects, 1981

# Grasping Funnels



# Grasp Synthesis

- Robot must select where to position hand for grasping
  - Hand pose and finger configuration
  - Contact locations on hand for placing objects
- Common inputs: vision and object models (cache grasps)

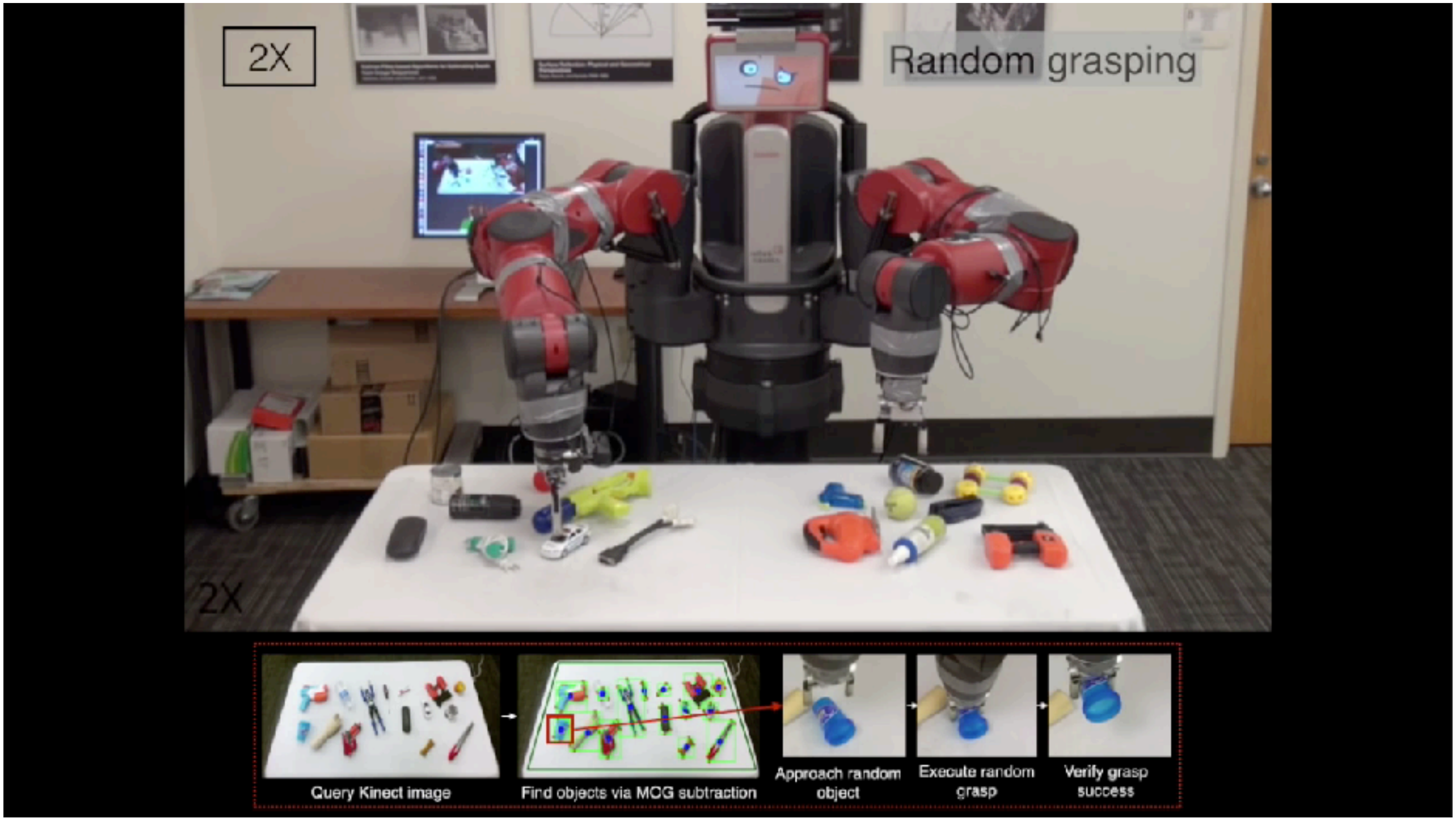


- Often implemented as sample and evaluate/classify grasps

Lenz et al., Deep Learning for Detecting Robotic Grasps, International Journal of Robotics Research 2015

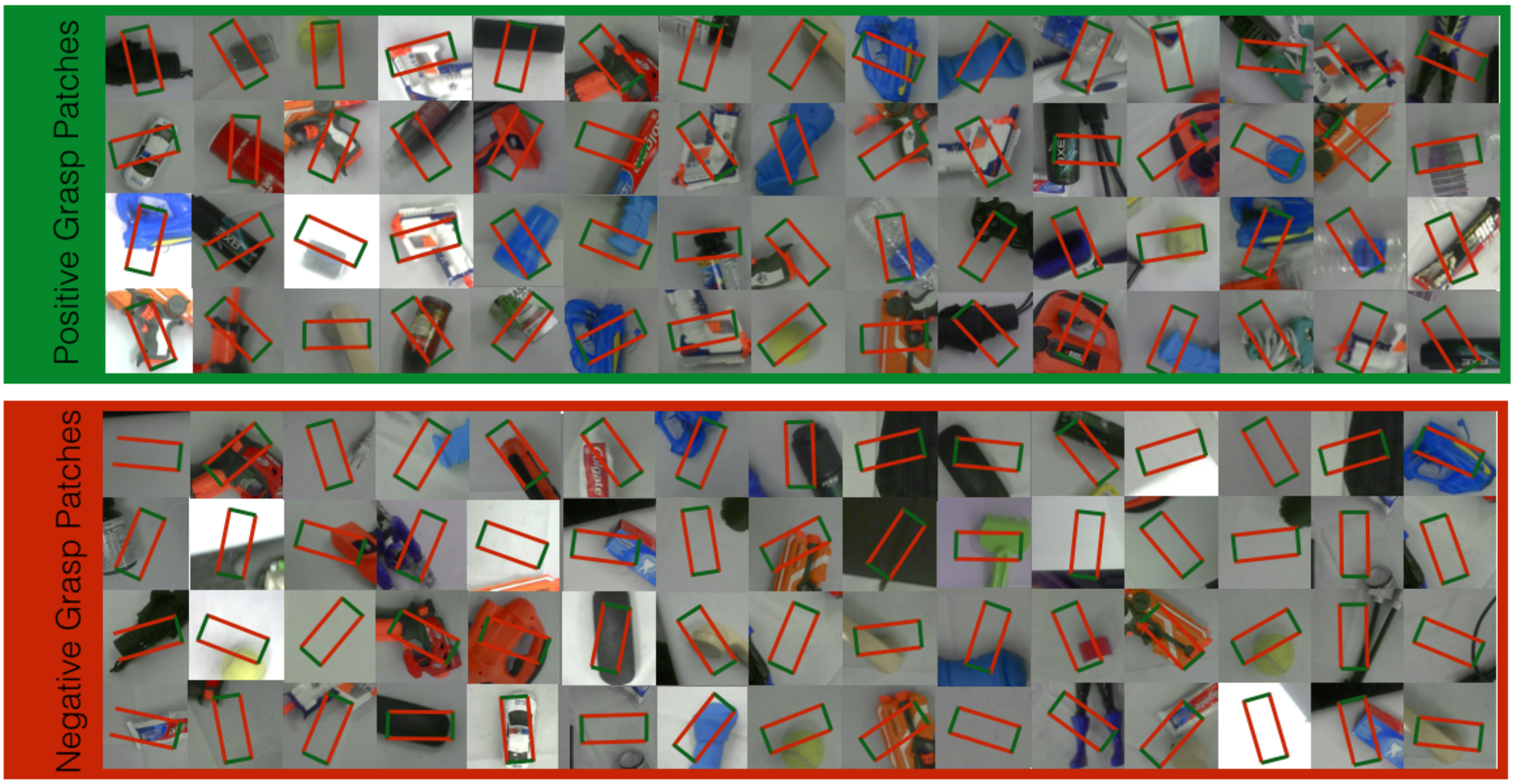
Miller et al., Automatic Grasp Planning using Shape Primitives, ICRA 2003

# Learning to Synthesize Grasps



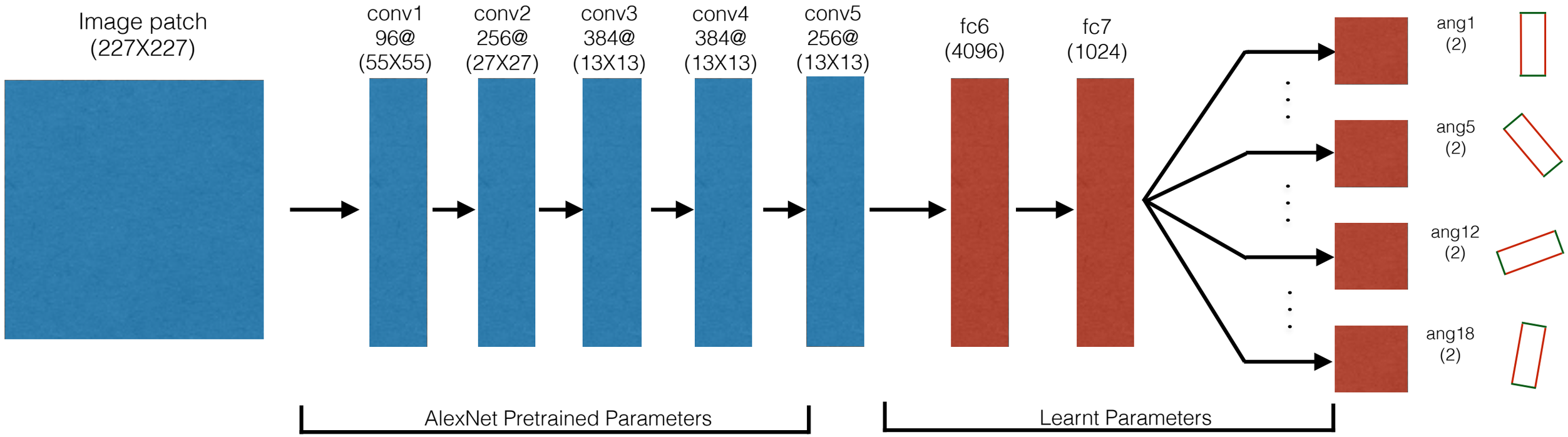

Pinto and Gupta, Supersizing Self-Supervision: Learning to Grasp from 50k tries and 700 Robot Hours, ICRA 2016

# Learning to Synthesize Grasps




Pinto and Gupta, Supersizing Self-Supervision: Learning to Grasp from 50k tries and 700 Robot Hours, ICRA 2016

# Convolutional Neural Networks




Pinto and Gupta, Supersizing Self-Supervision: Learning to Grasp from 50k tries and 700 Robot Hours, ICRA 2016

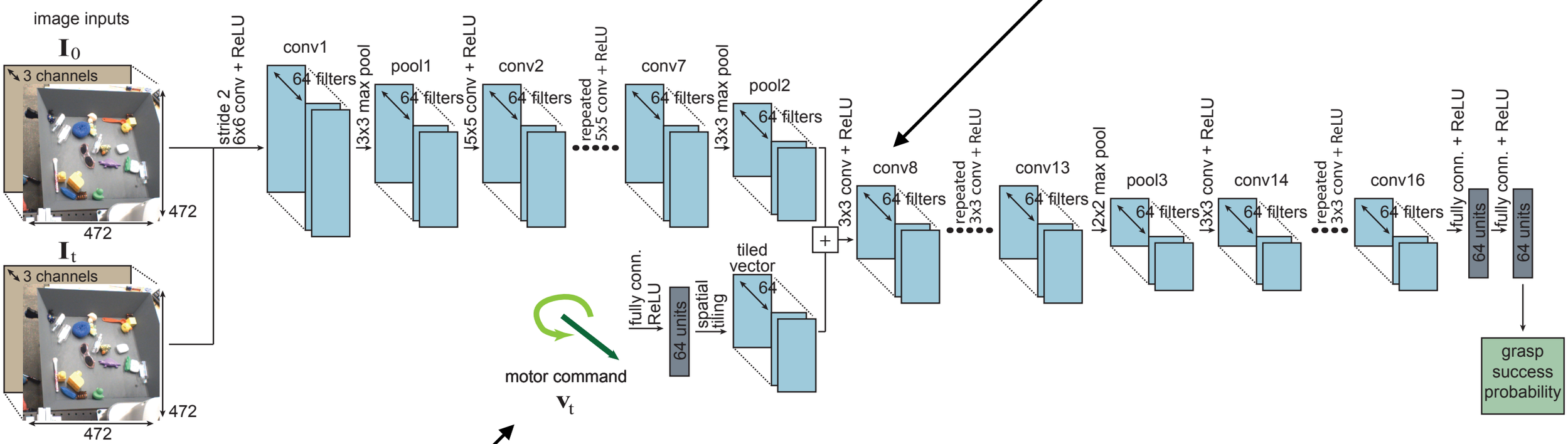
# Convolutional Neural Networks


Pinto and Gupta, Supersizing Self-Supervision: Learning to Grasp from 50k tries and 700 Robot Hours, ICRA 2016

# CNNs with Actions

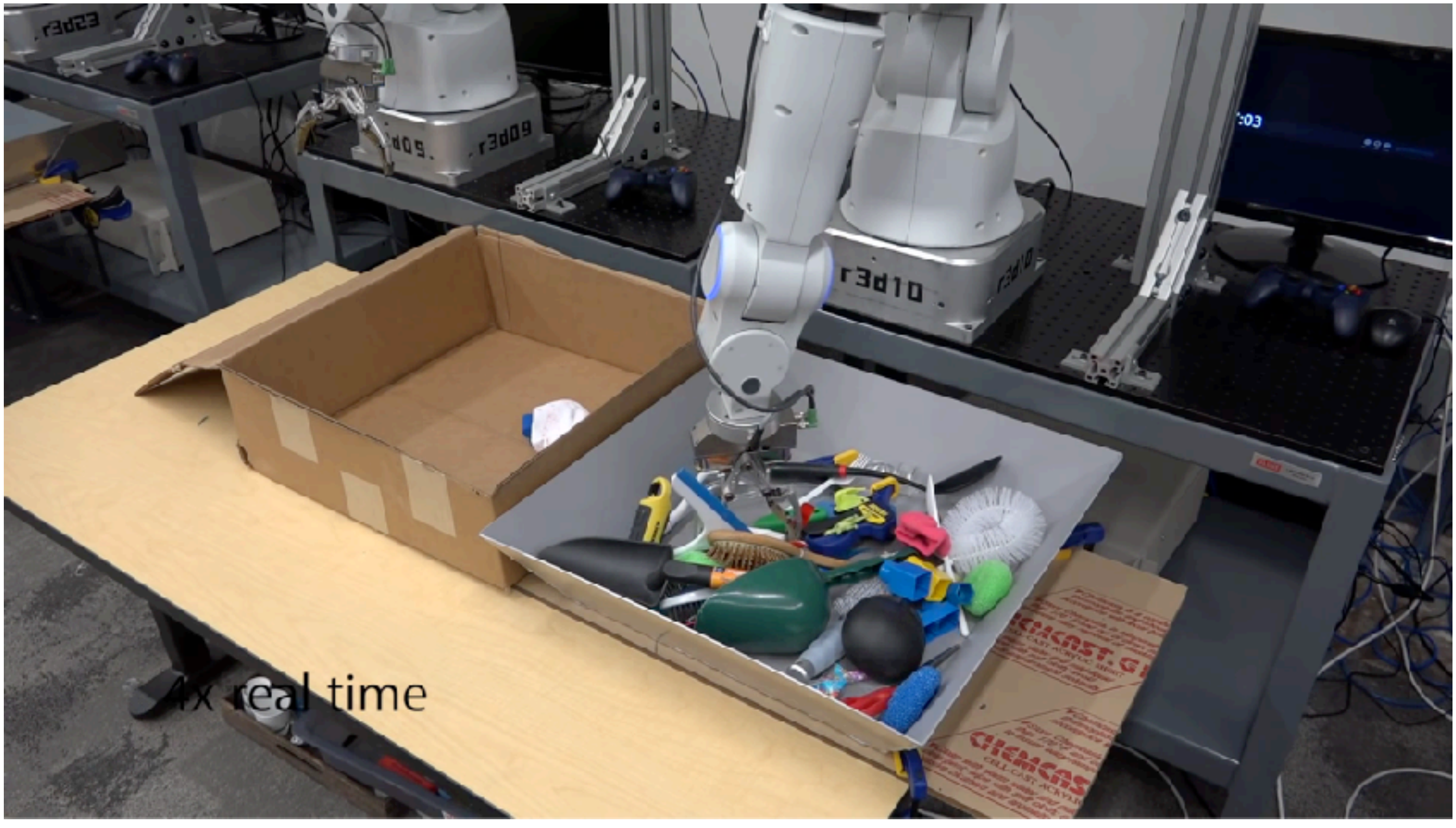
Levine et al., Learning Hand-Eye Coordination for Grasping with Deep Learning and Large-Scale Data Collection IJRR 2017

# CNNs with Actions




Levine et al., Learning Hand-Eye Coordination for Grasping with Deep Learning and Large-Scale Data Collection IJRR 2017

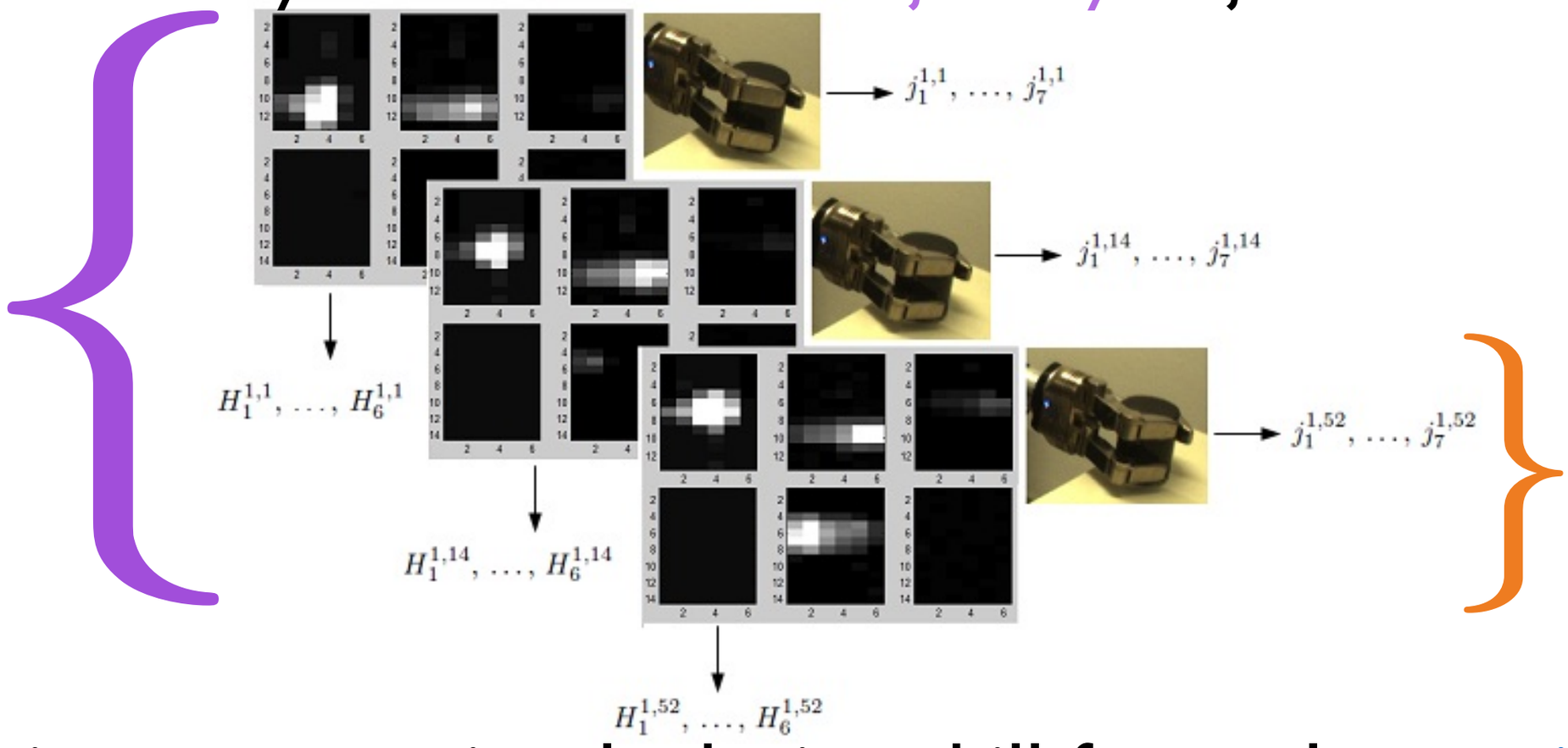
# CNNs with Actions




Levine et al., Learning Hand-Eye Coordination for Grasping with Deep Learning and Large-Scale Data Collection IJRR 2017

# Grasp Outcome Detection

- Estimate skill's outcome (success/fail) from sensory data
  - Use sensory data from entire trajectory or just the final step

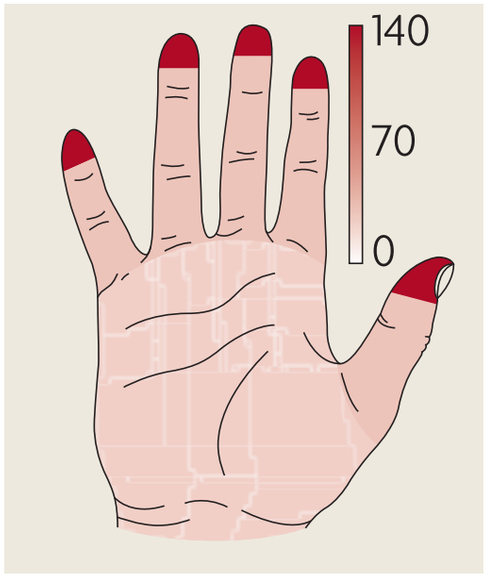
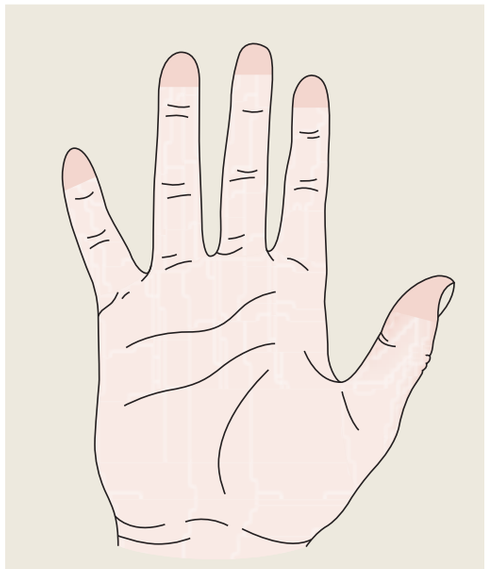
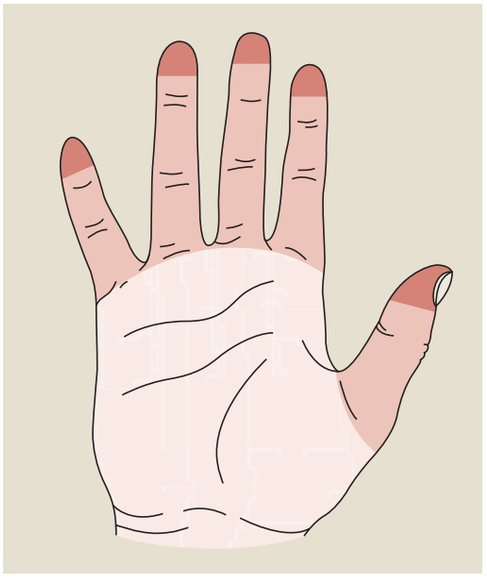
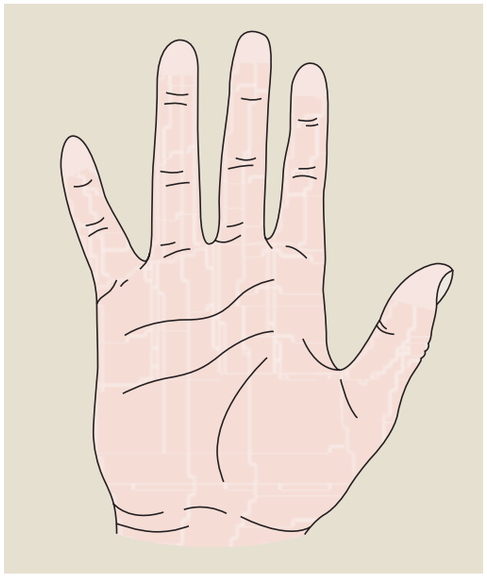



- Monitor sensor signals during skill for early termination
  - Useful when working under uncertainty, e.g., object positions
  - Avoid making mistakes or making them worse

Bekiroglu et al. Assessing Grasp Stability Based on Learning an Haptic Data, Transactions on Robotics 2011

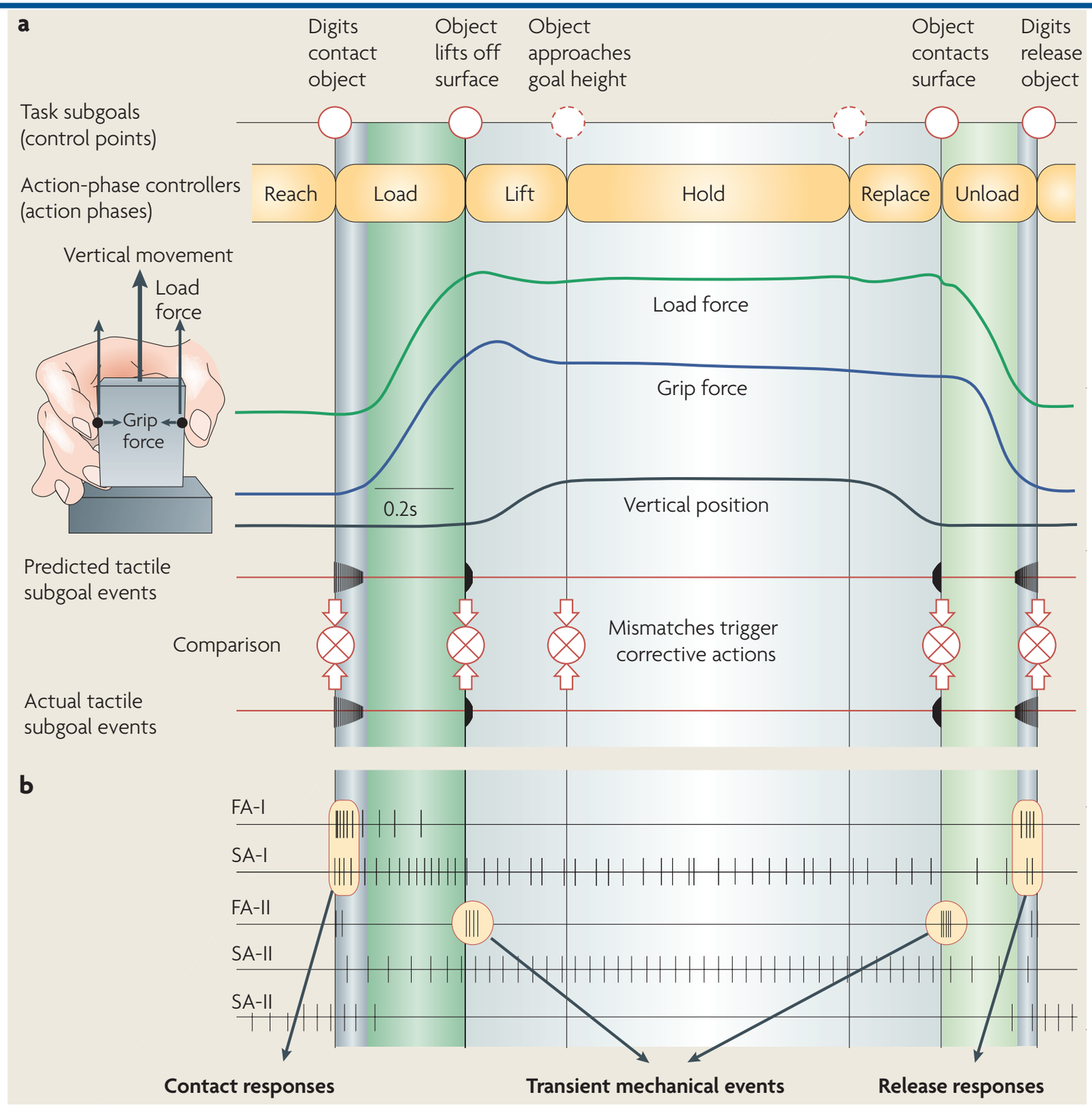
# Tactile Afferents

- Tactile afferents in human (afferents per $cm^2$)

| Fast Afferents | | Slow Afferents | |
|---|---|---|---|
| FA-I | FA-II | SA-I | SA-II |
|   |  |  |  |
| Local Discontinuities | Object Vibrations | Local Shape | Skin stretch |
| ~5-50 Hz | ~40-400 Hz | ~<5 Hz | |

R. Johansson and J. Flanagan; Coding and use of tactile signals from the fingertips in object manipulation, Nature Reviews Science 2009

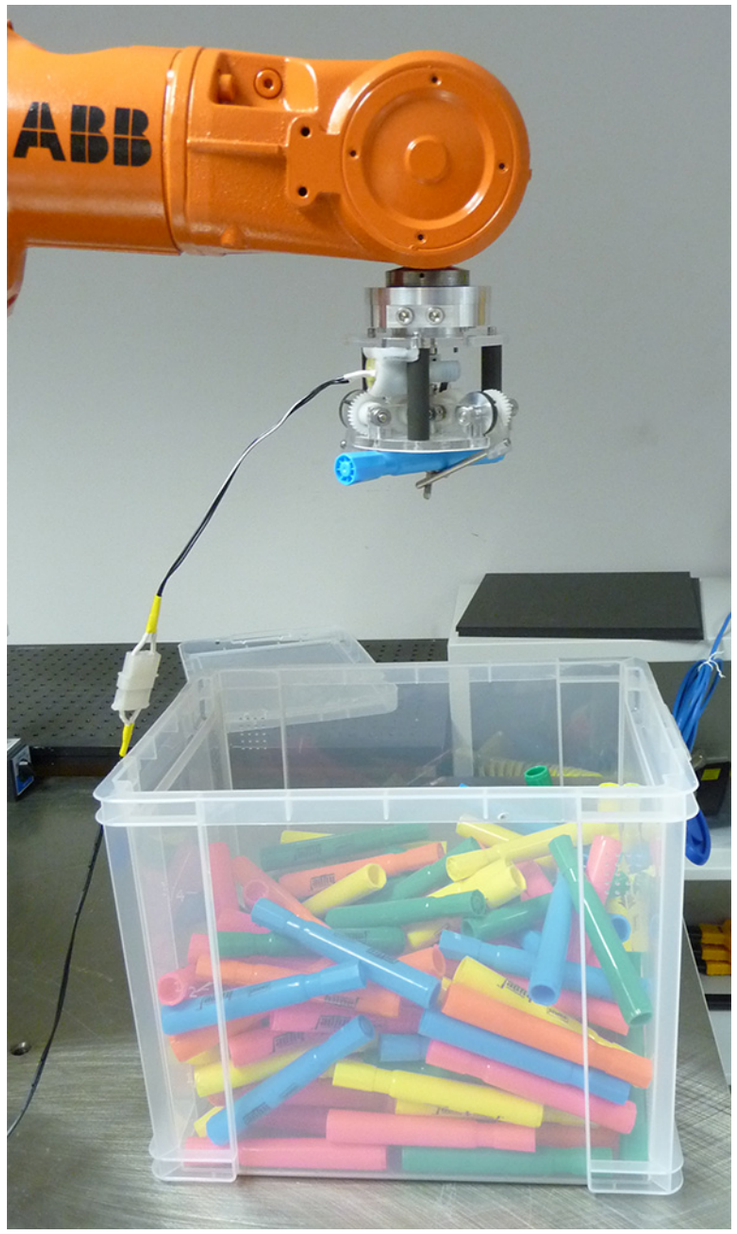
# Tactile Afferents and Contact Events

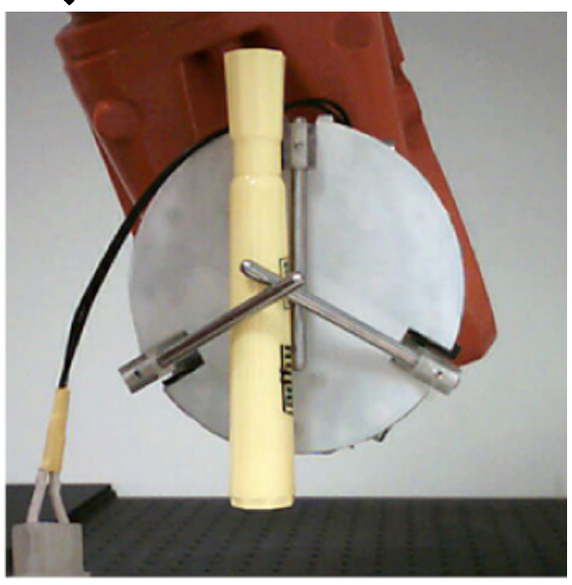



R. Johansson and J. Flanagan; Coding and use of tactile signals from the fingertips in object manipulation, Nature Reviews Science 2009

# Blind Grasping

- Some environments afford many grasps in a small area
  - Grasping from piles of objects or bin picking
  - High probability of simple grasp succeeding
  - May accidentally grasp multiple objects
- Focus on (blind) outcome detection
  - Grasp success and object localization

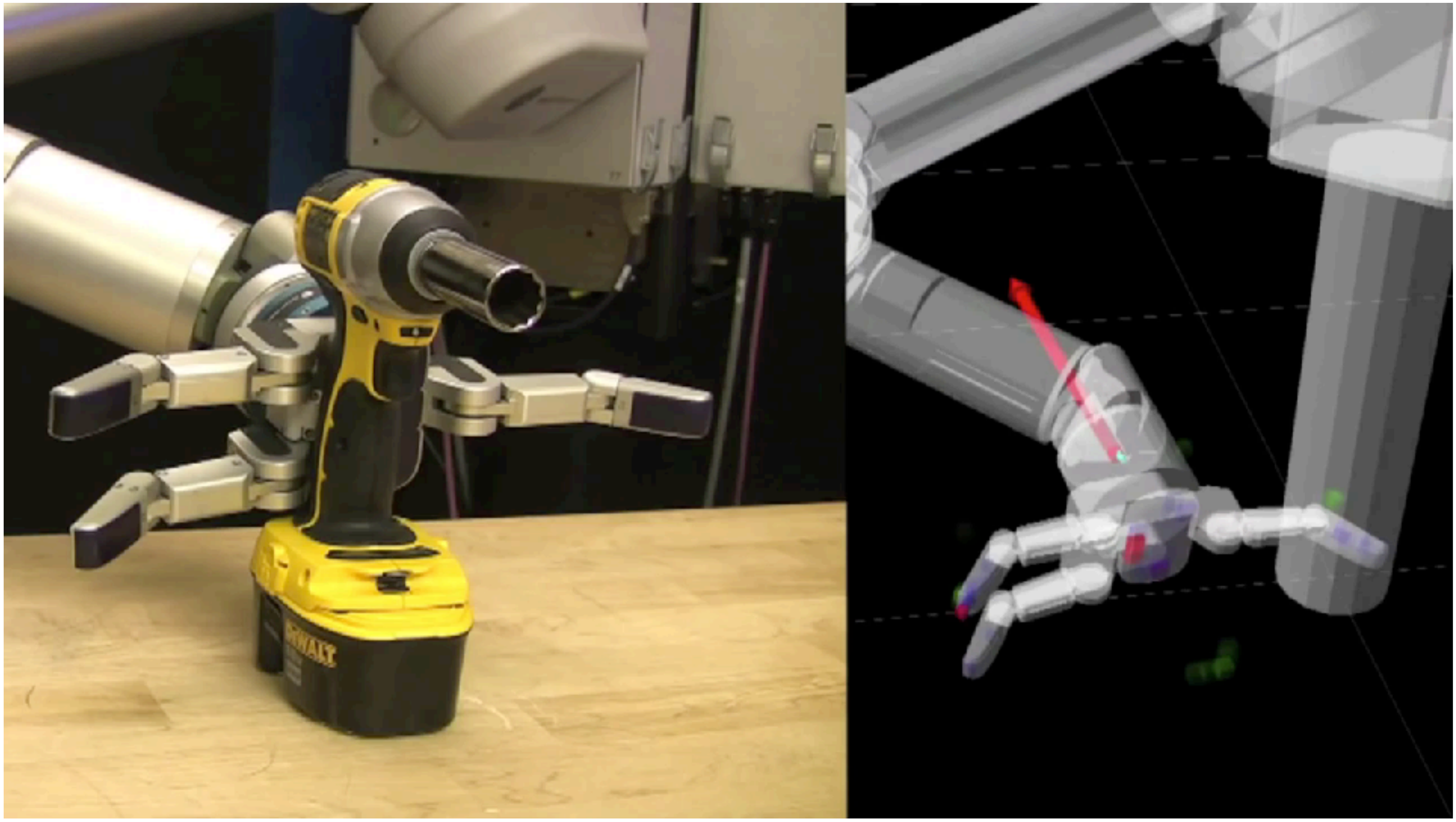


Rodriguez et al., Manipulation Capabilities with Simple Hands, ISER 2010

Mason et al., Generality and Simple Hands, CMU Tech Report 2009

# Grasp Outcome Detection



Pastor et al. Towards Learning Associative Skill Memories, Humanoids 2012

# Exploit Environment and Compliance

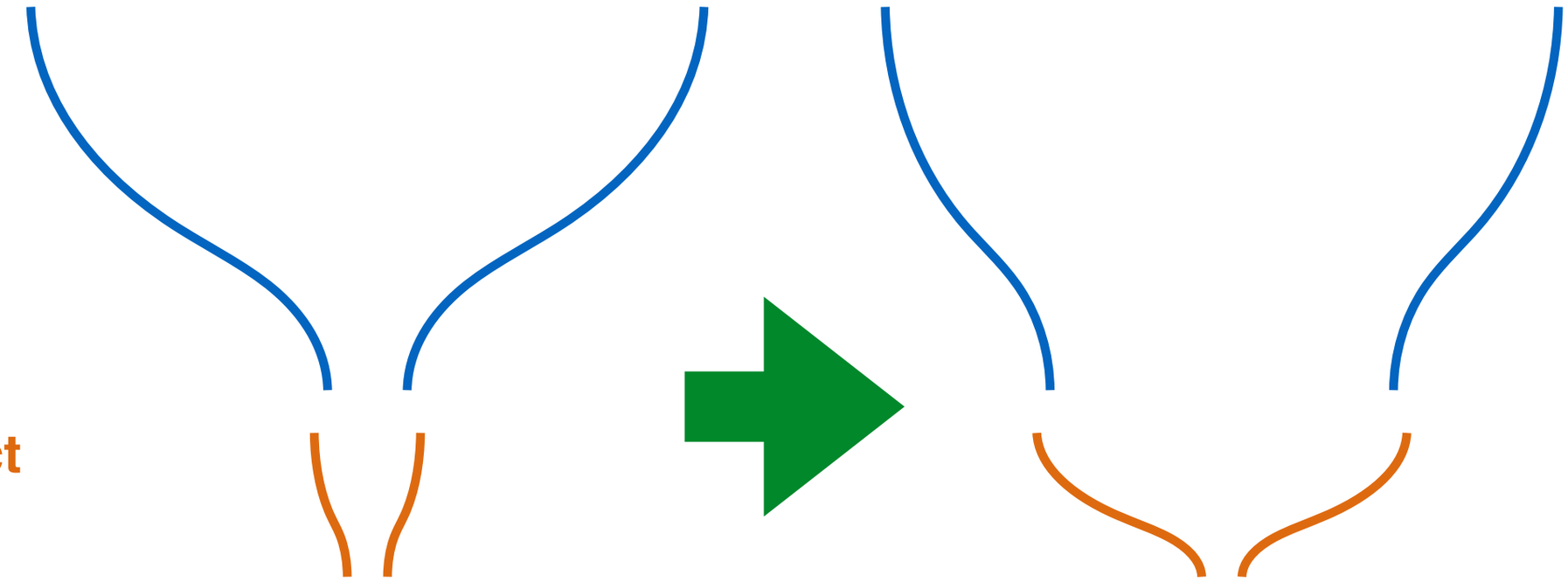
"Put the fingers in the right place"

"Let the fingers fall where they may"

**Initial Configurations**

**Initial Configurations**

**Reaching in Free Space**



**Pre-grasp Object Interactions**

**Successful Grasps**

**Successful Grasps**

## More Robust Grasping Strategies

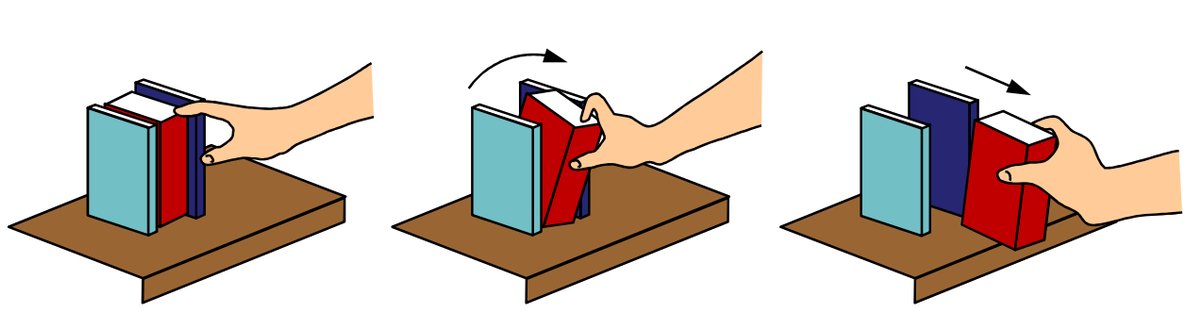
(less reliance on accurate models, sensing and control)

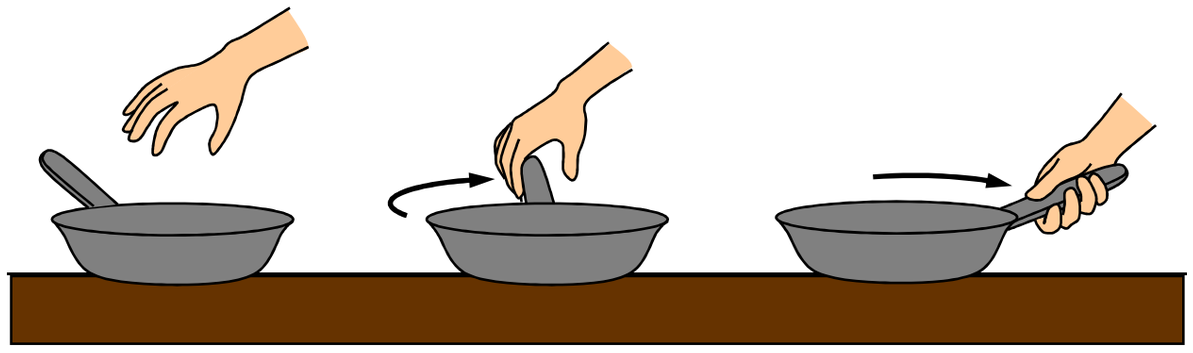
Rodriguez et al., Manipulation Capabilities with Simple Hands, ISER 2010

Eppner et al., A Compliance-centric View of Grasping, TUBerlin Tech Report, 2012

# Push Grasping

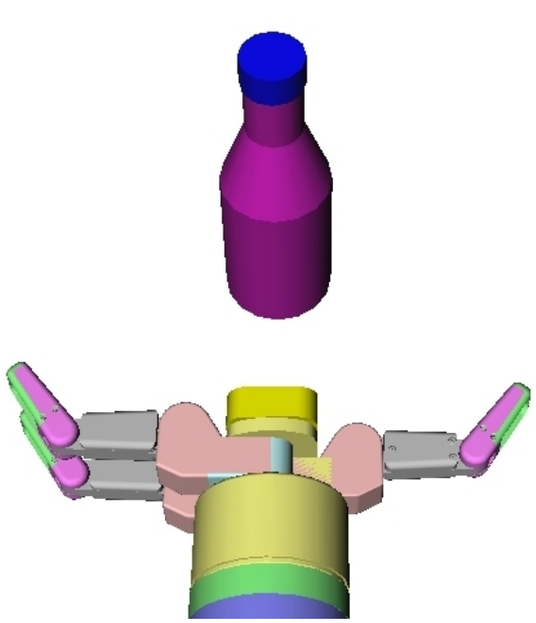
- Pre-grasp manipulations reconfigure objects before grasping

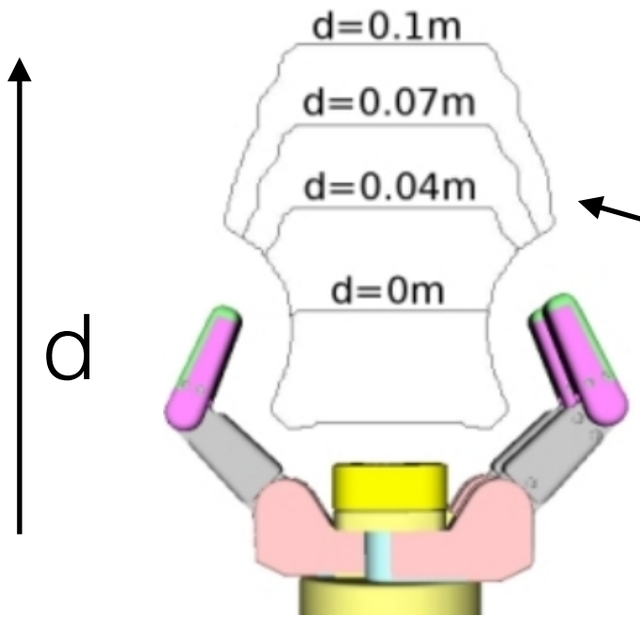




  - Allow agent to then perform better or more robust grasps

- Slide objects on horizontal surfaces for robust grasping



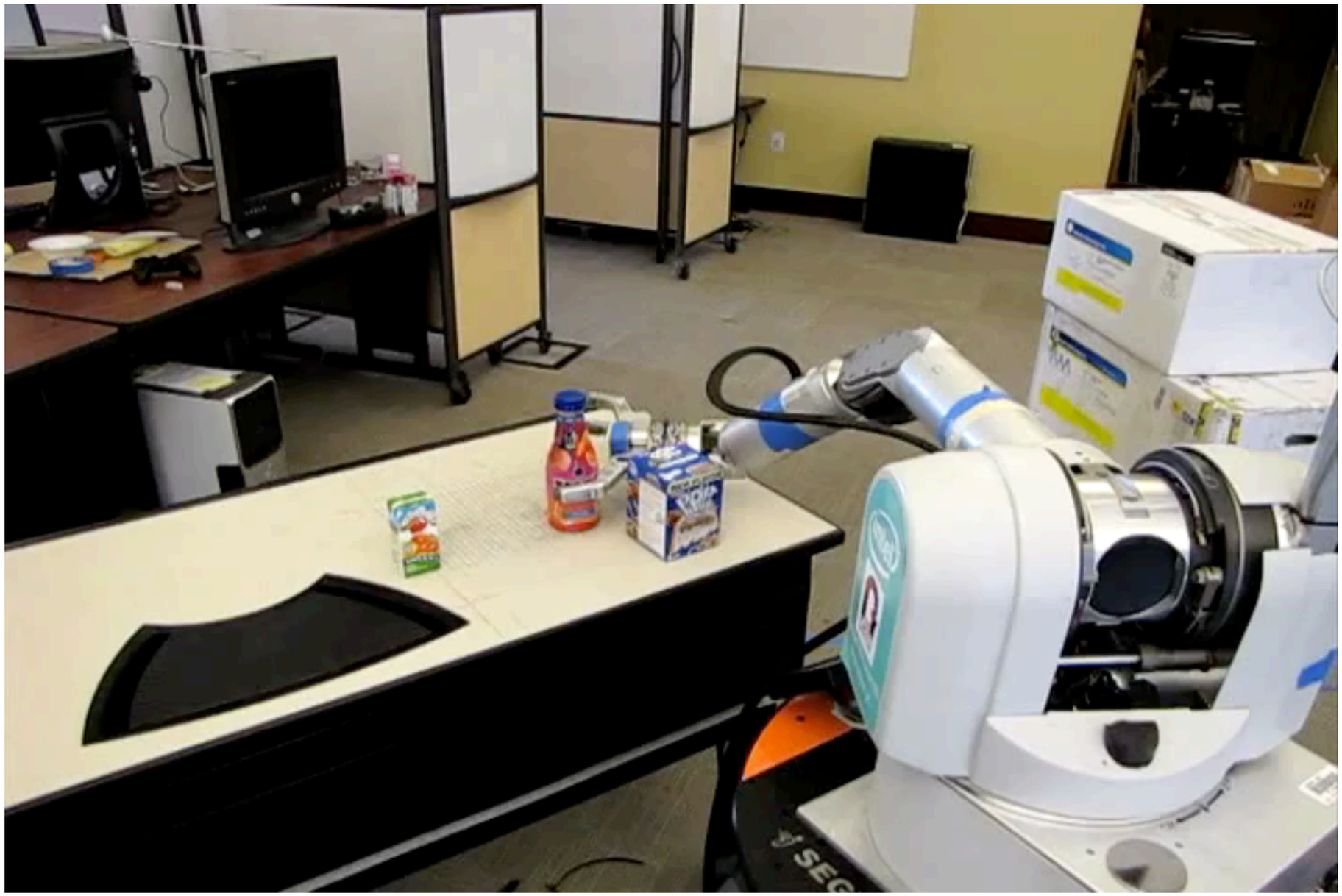



**Capture Regions for Bottle**

L. Chang, Pre-grasp Interaction as a Manipulation Strategy for Movable Objects, Ph.D. Thesis 2010

Dogar and Srinivasa, Push Grasping with Dexterous Hands: Mechanics and a Method,IROS 2010

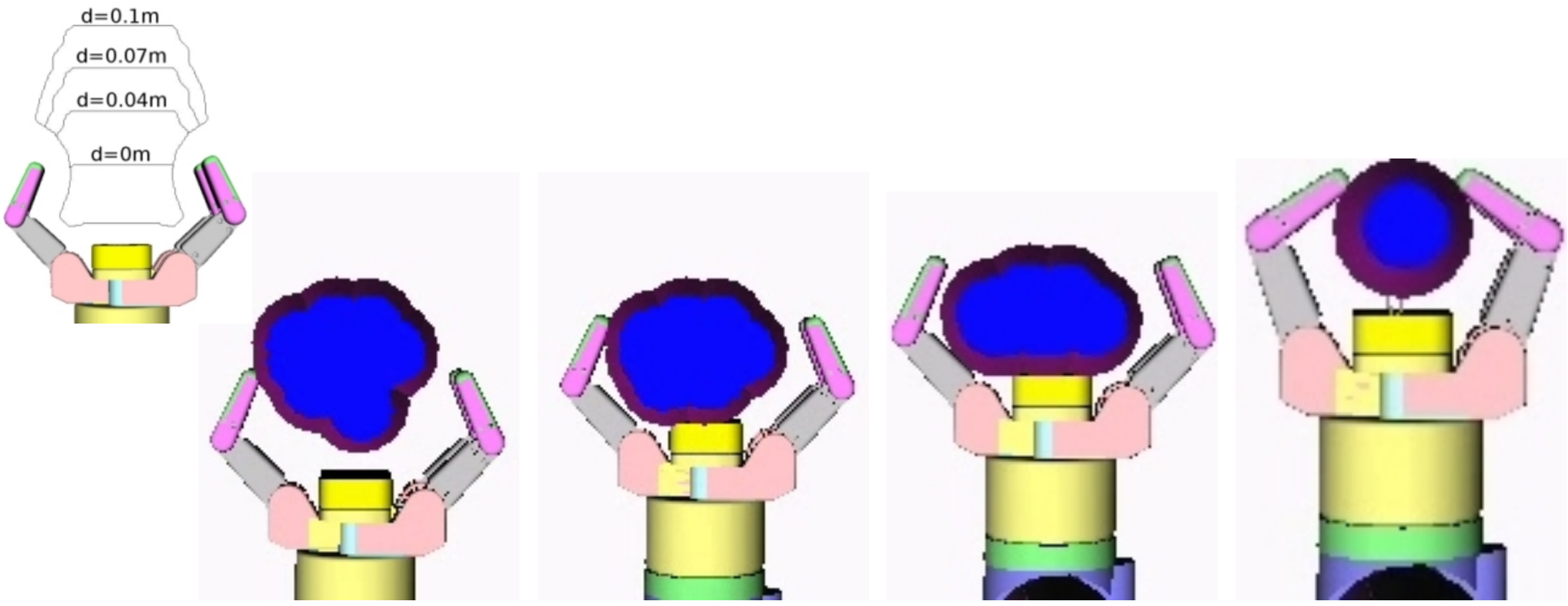
# Push Grasping



Dogar and Srinivasa, Push Grasping with Dexterous Hands: Mechanics and a Method,IROS 2010

# Push-Grasping

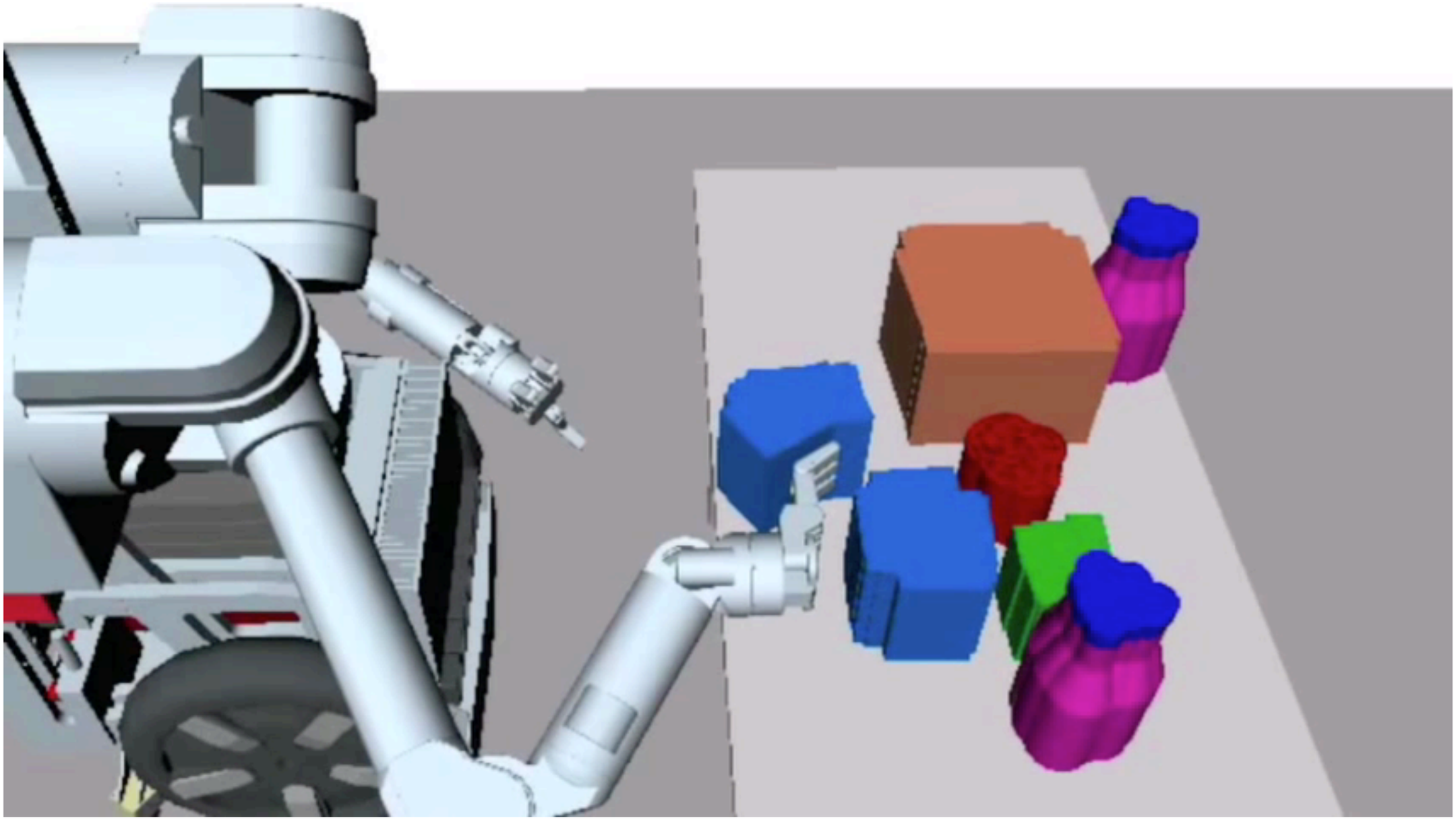
- Capture region acts as a position uncertainty funnel




Dogar and Srinivasa, A Framework for Push Grasping in Clutter, RSS 2011

# Push-Grasping

- Can also use pushing actions to move uncertain clutter

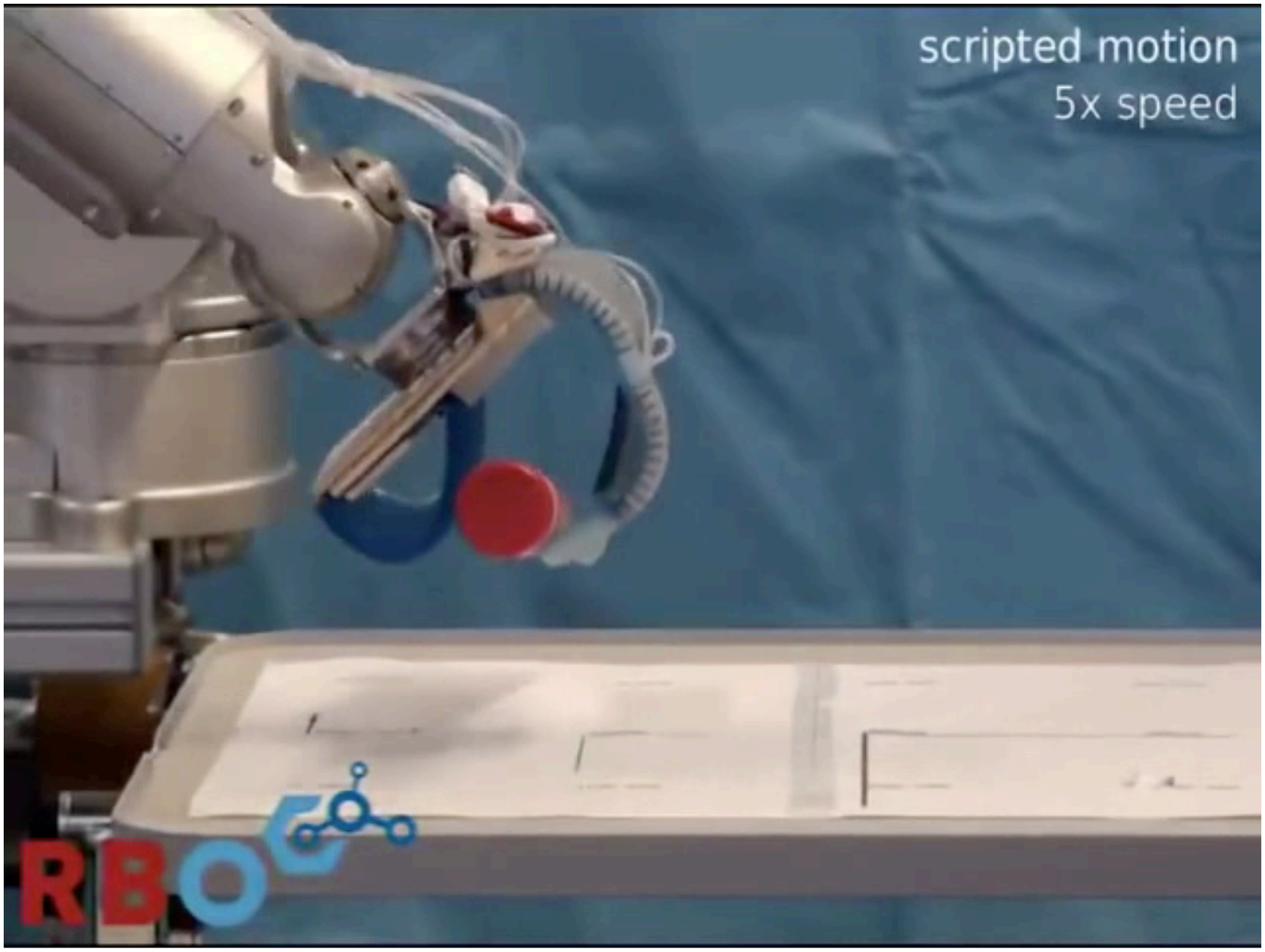


Dogar and Srinivasa, A Framework for Push Grasping in Clutter, RSS 2011

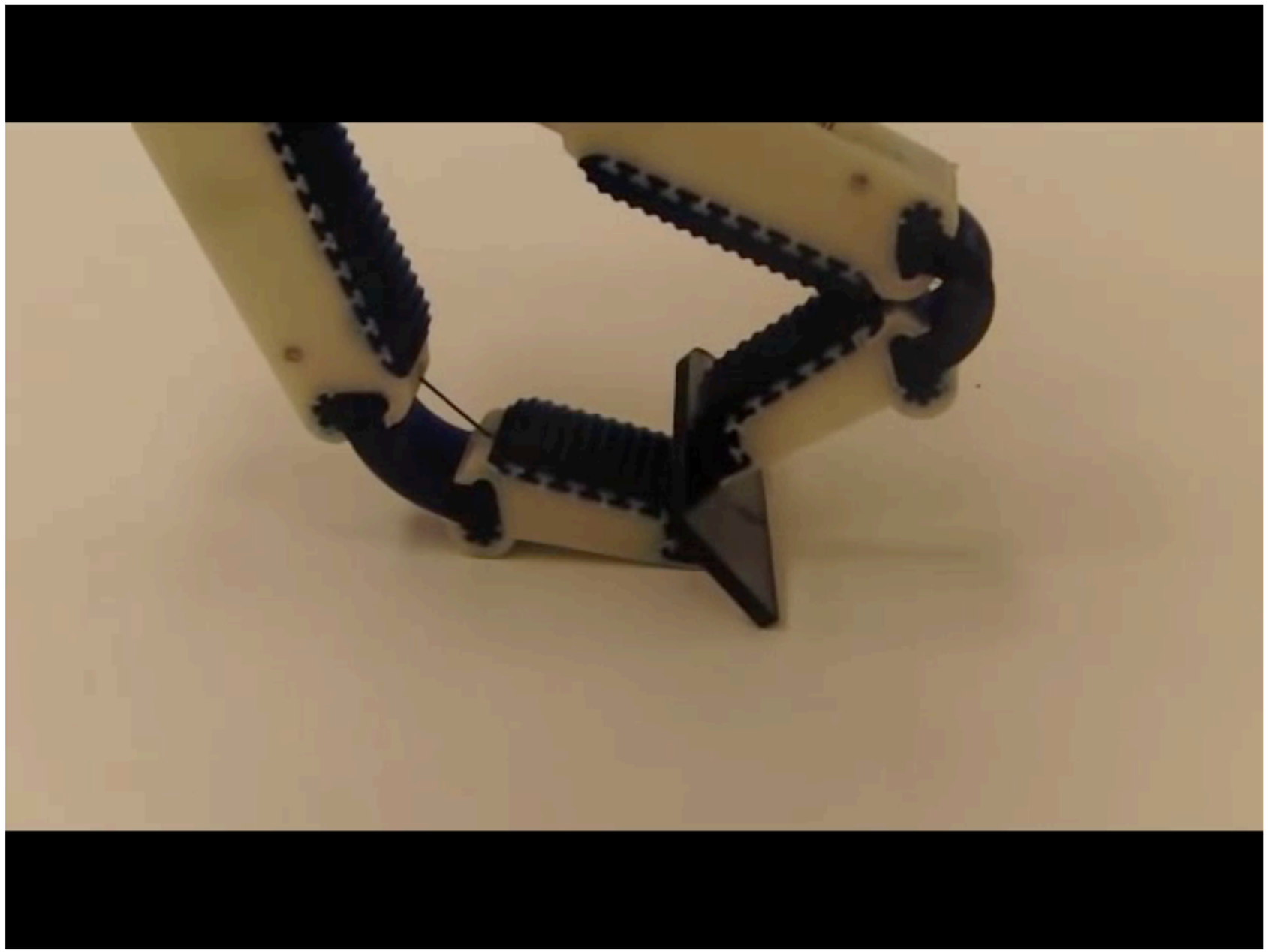
# Tabletop Grasps and Compliance

- Object and hand need to have complementary shape
  - Object compliance and sliding allow object to adapt to hand
  - Hand compliance allows hand to adapt to object
- Compliance also allows for adapting to environment
  - Vertical constraint of table aligns object and hand
  - Exploit environmental constraints to achieve certain grasps

# Tabletop Grasps and Compliance



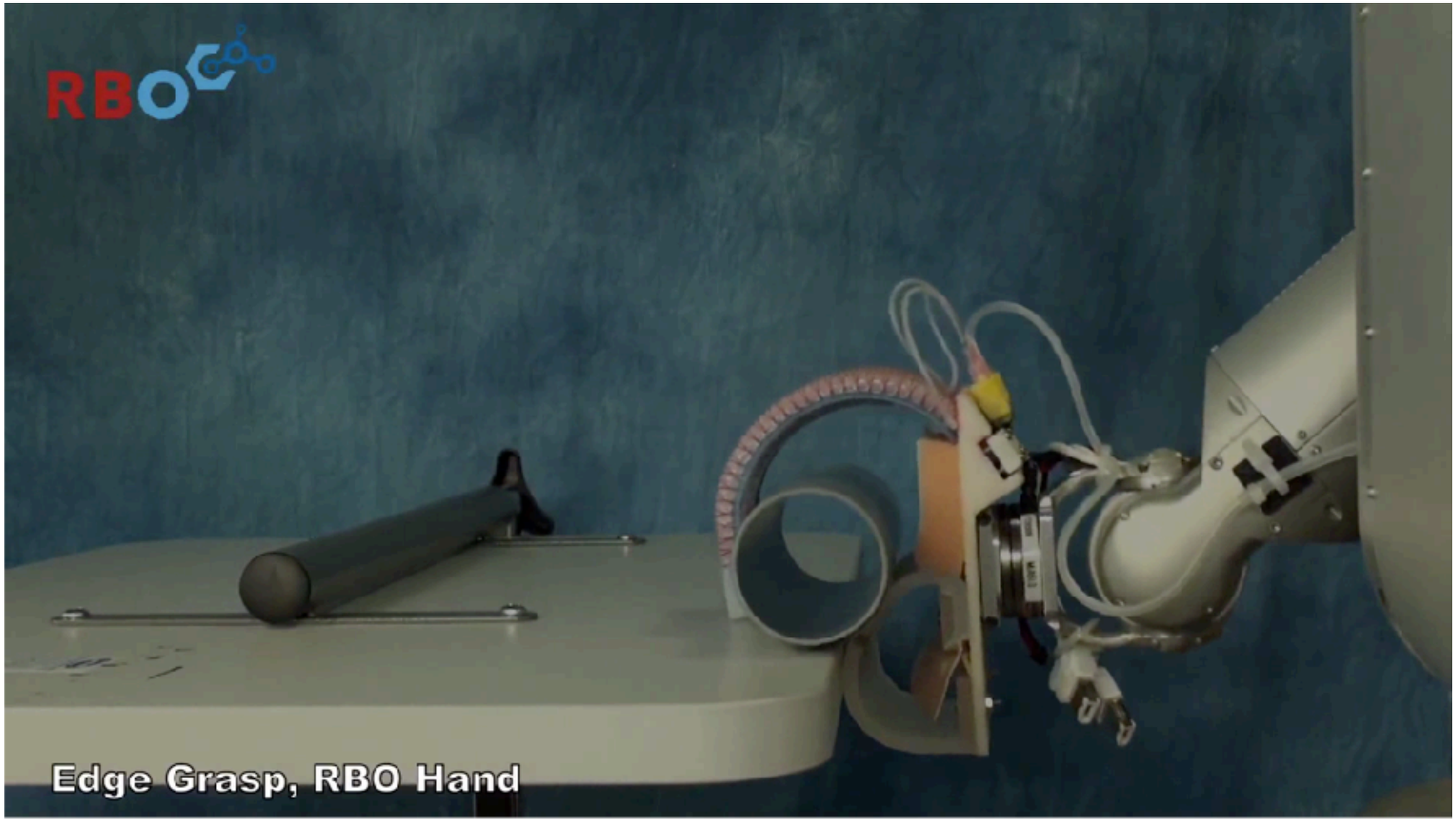
# Flip and Pinch Grasps



R. Ma et al., Dexterous Manipulation with Underactuated Fingers: Flip-and-Pinch Task, ICRA 2012

# Pre-Grasp Manipulations

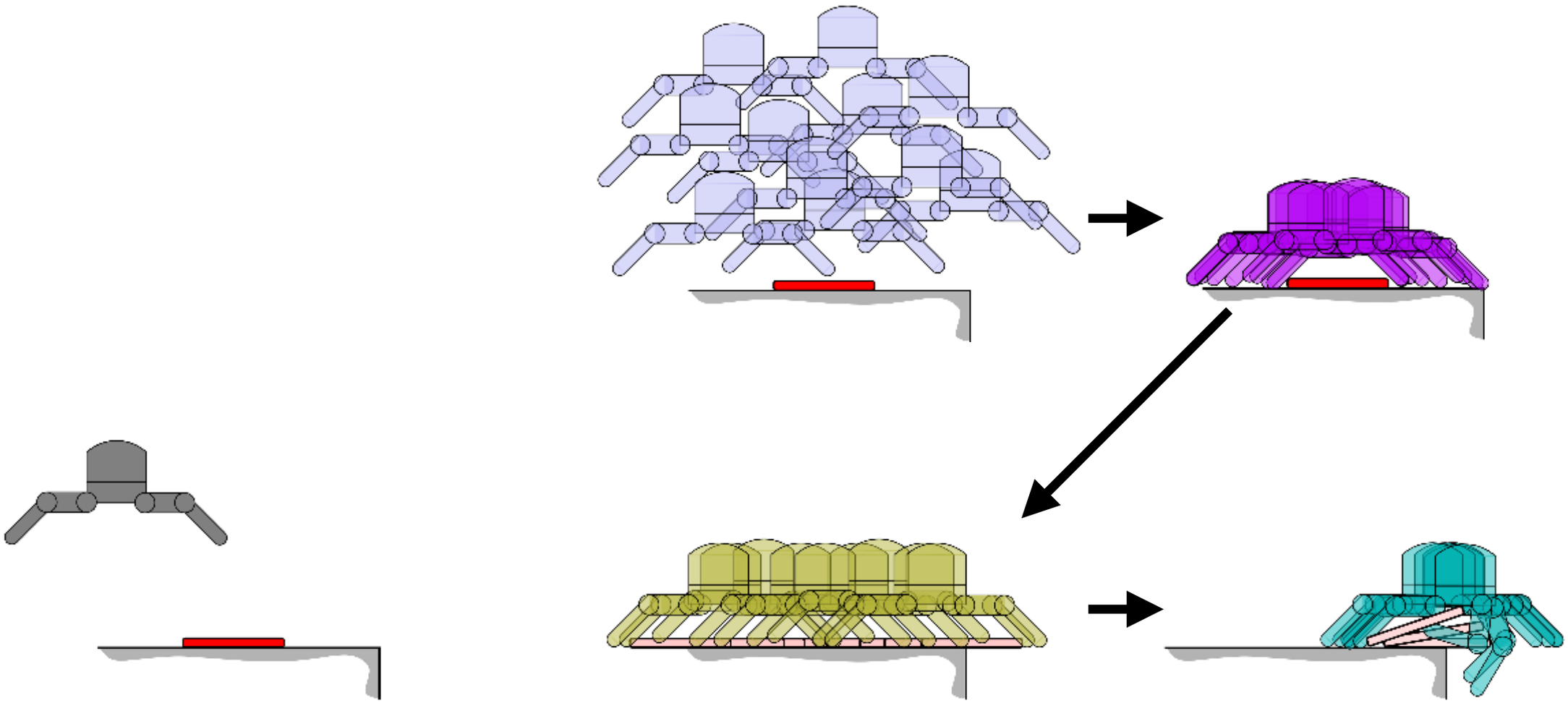
- Can exploit a variety of other constraints as well




Eppner et al., Exploitation of Environmental Constraints in Human and Robot Grasping, IJRR 2015

# Exploiting Environmental Constraints

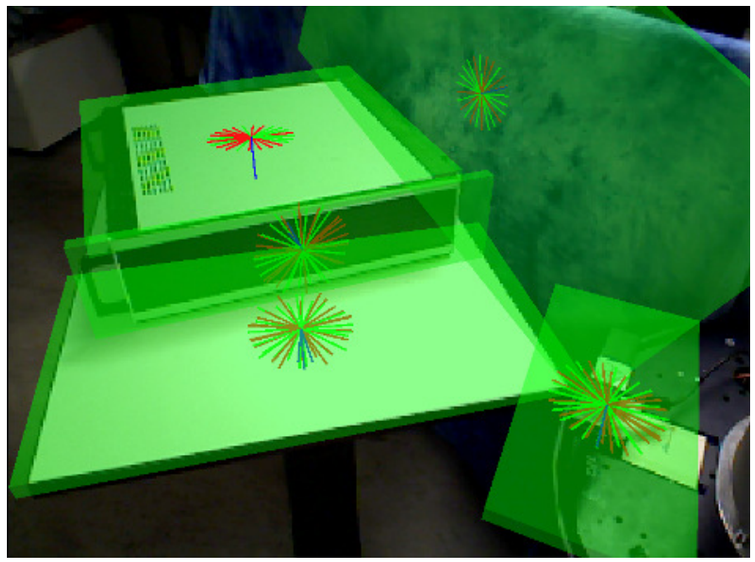
- Environments afford multiple constraints / interactions



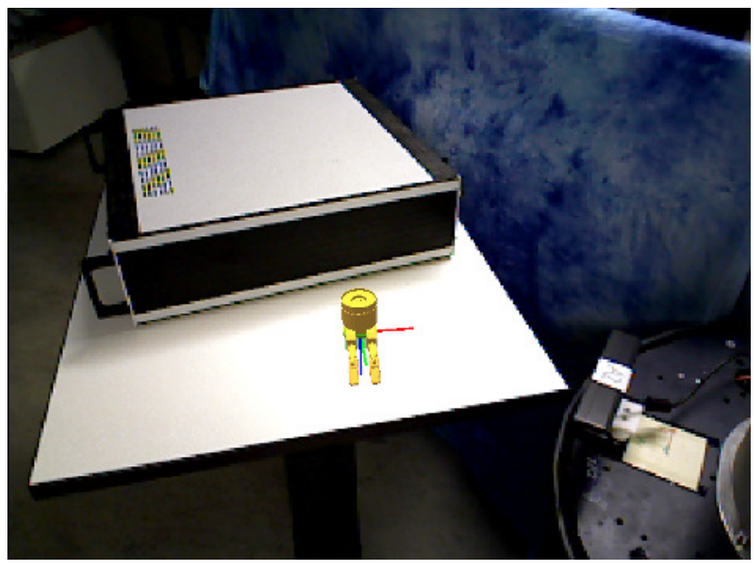
- Transition between constraints to perform grasping task

# Exploiting Environmental Constraints

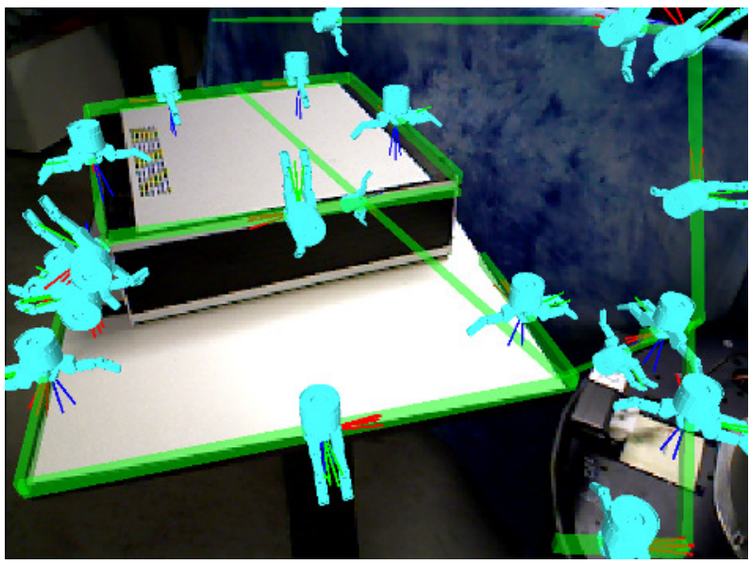
- Identify constraints based on scene geometry



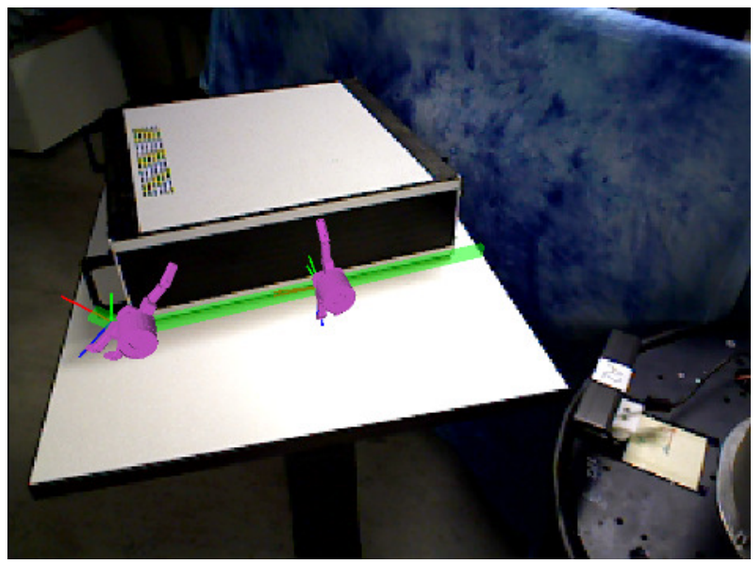
Sliding



Surface Grasp



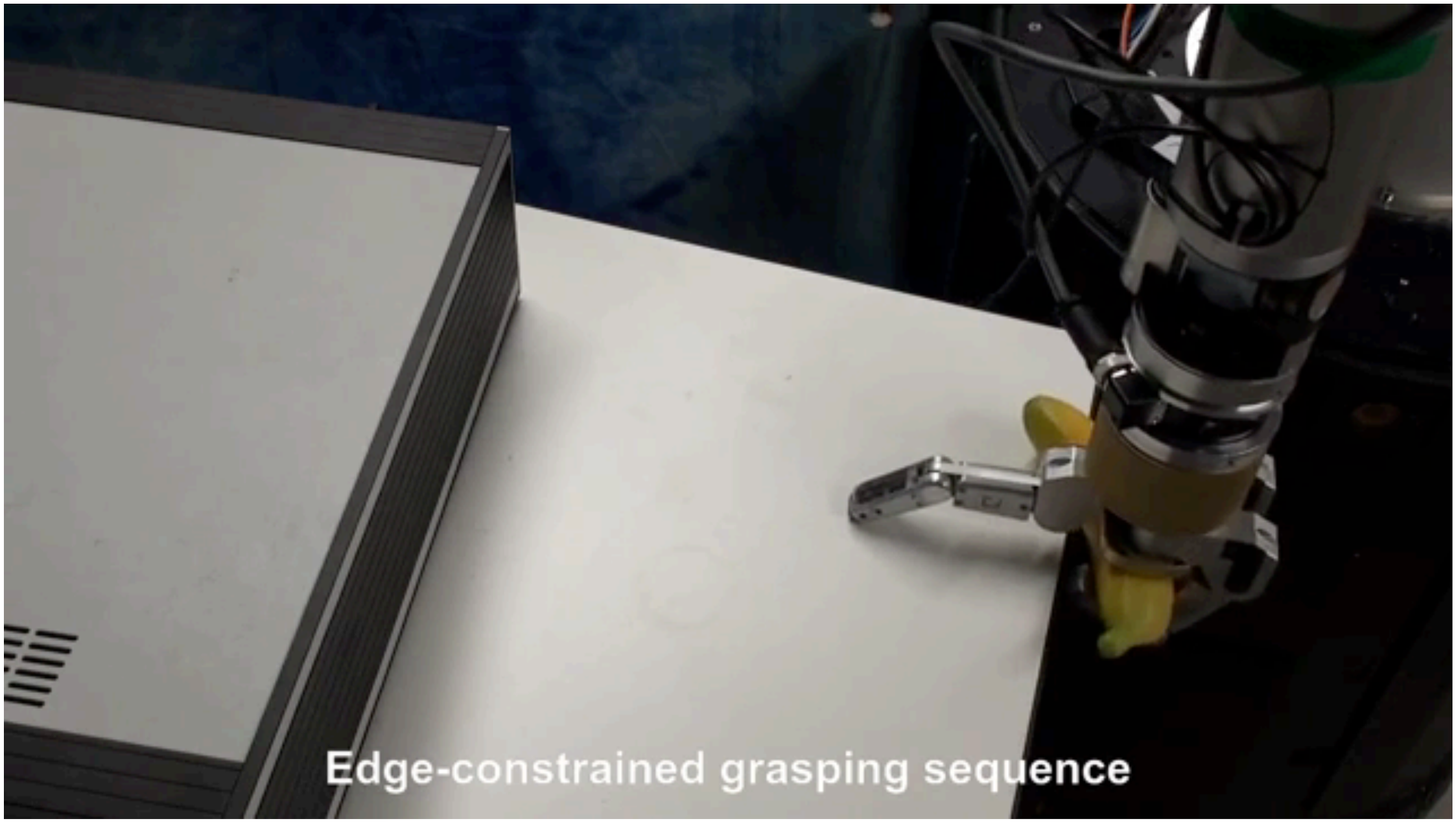
Edge Grasp



Wall Grasp

Eppner and Brock, Planning Grasp Strategies that Exploit Environmental Constraints, ICRA 2015

# Exploiting Environmental Constraints




Eppner and Brock, Planning Grasp Strategies that Exploit Environmental Constraints, ICRA 2015

# Questions?