

End-to-End Dexterous Manipulation with Deliberate Interactive Estimation



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2. Mechanical and Civil Engineering, California Institute of Technology.

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Government sponsorship acknowledged



Six Teams:

Carnegie Mellon University

HRL Laboratories

iRobot

Jet Propulsion Laboratory

SRI International

University of Southern California

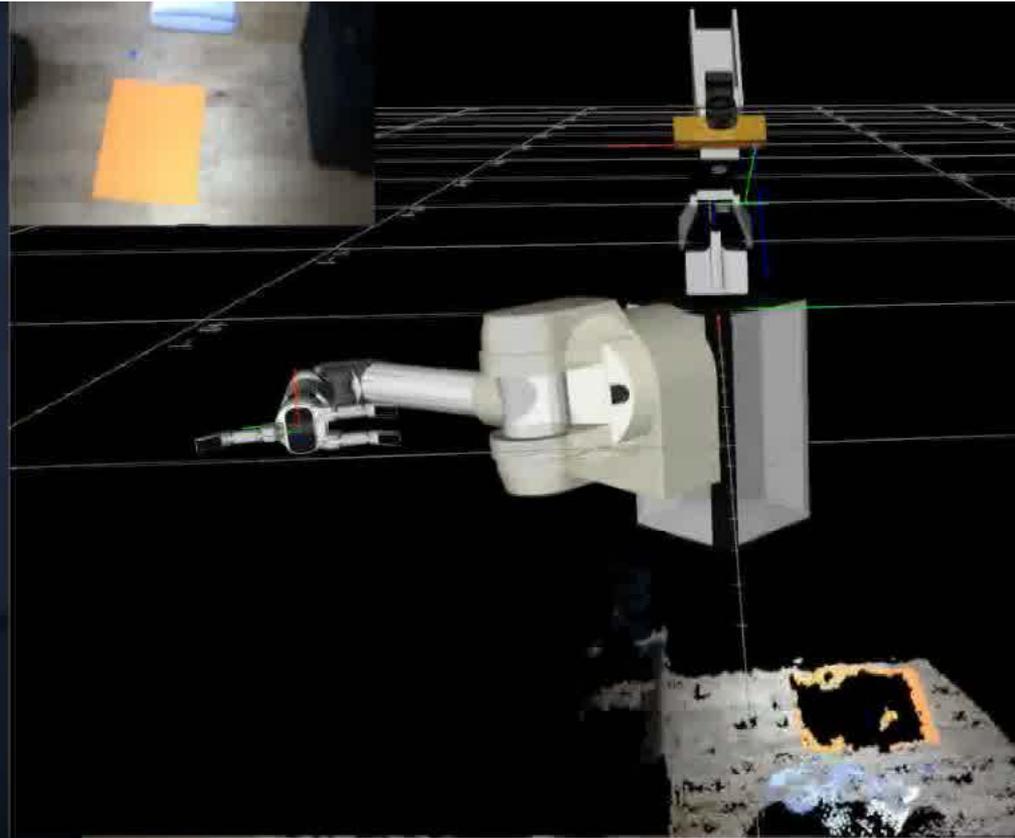
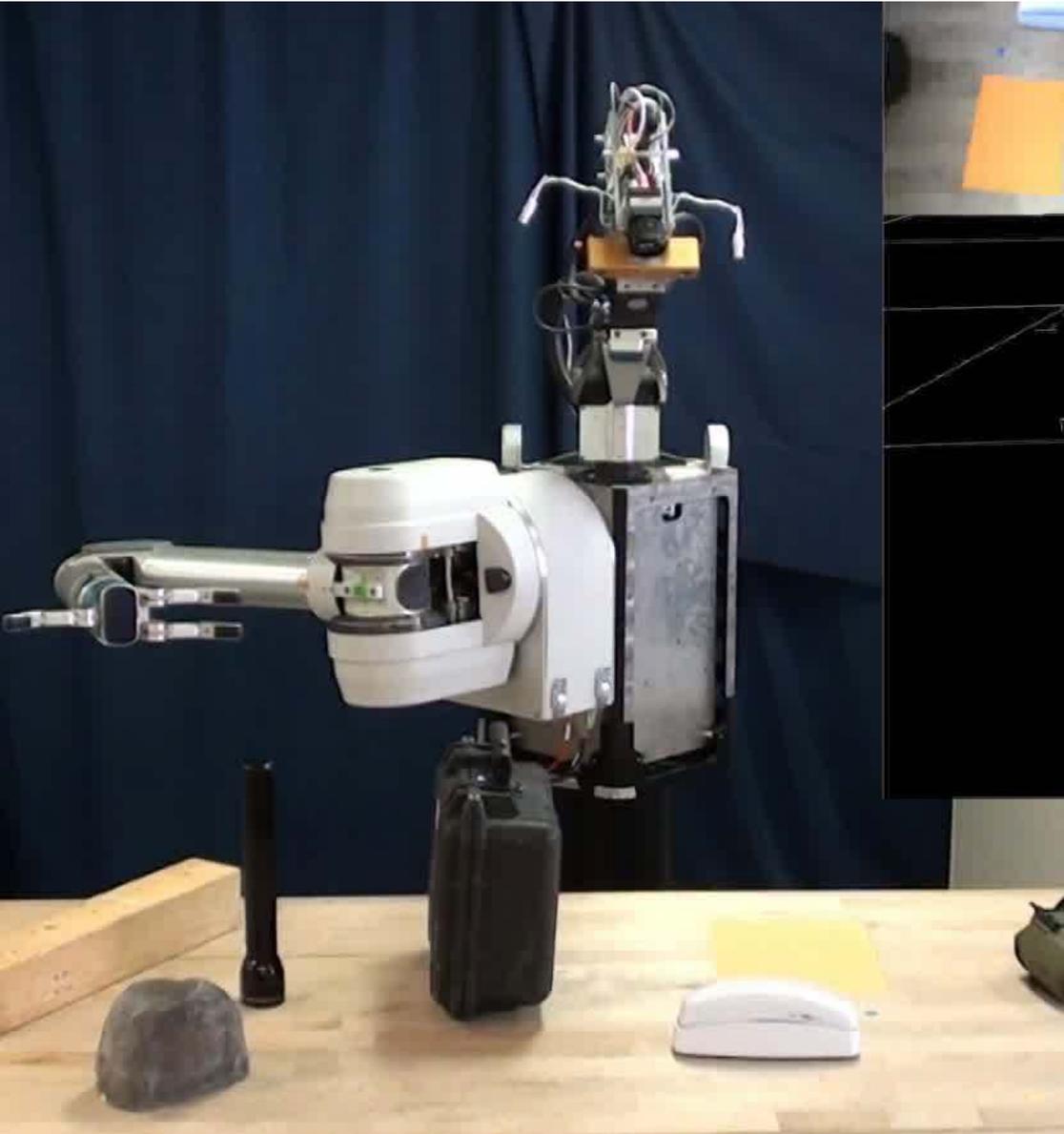
All teams provided same GFE:
identical robots and test objects

Each team creates and refines
algorithms at its own facility

Teams send code to DARPA's test
facility for evaluation



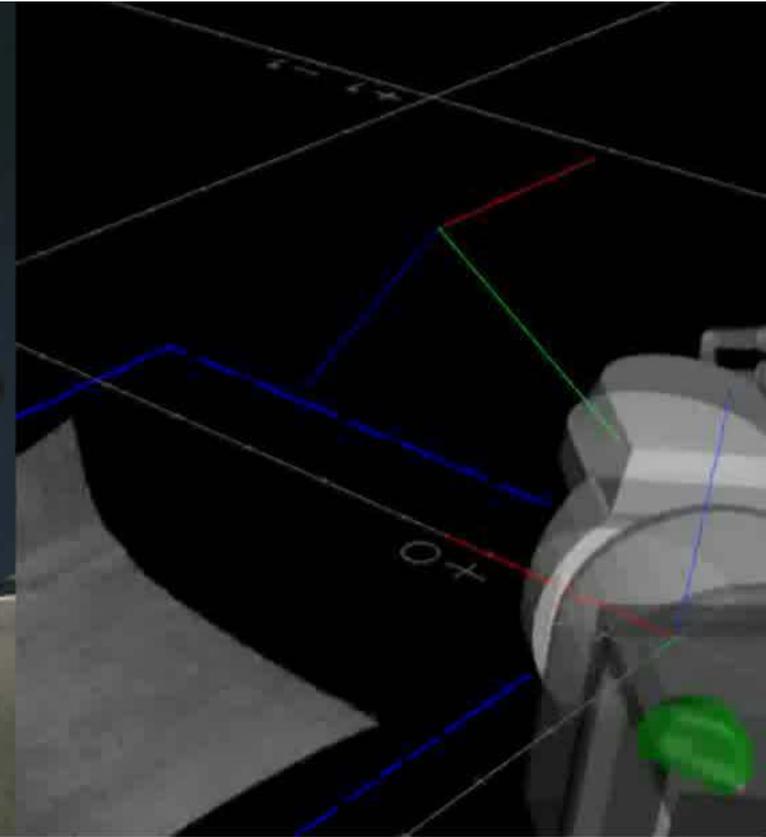
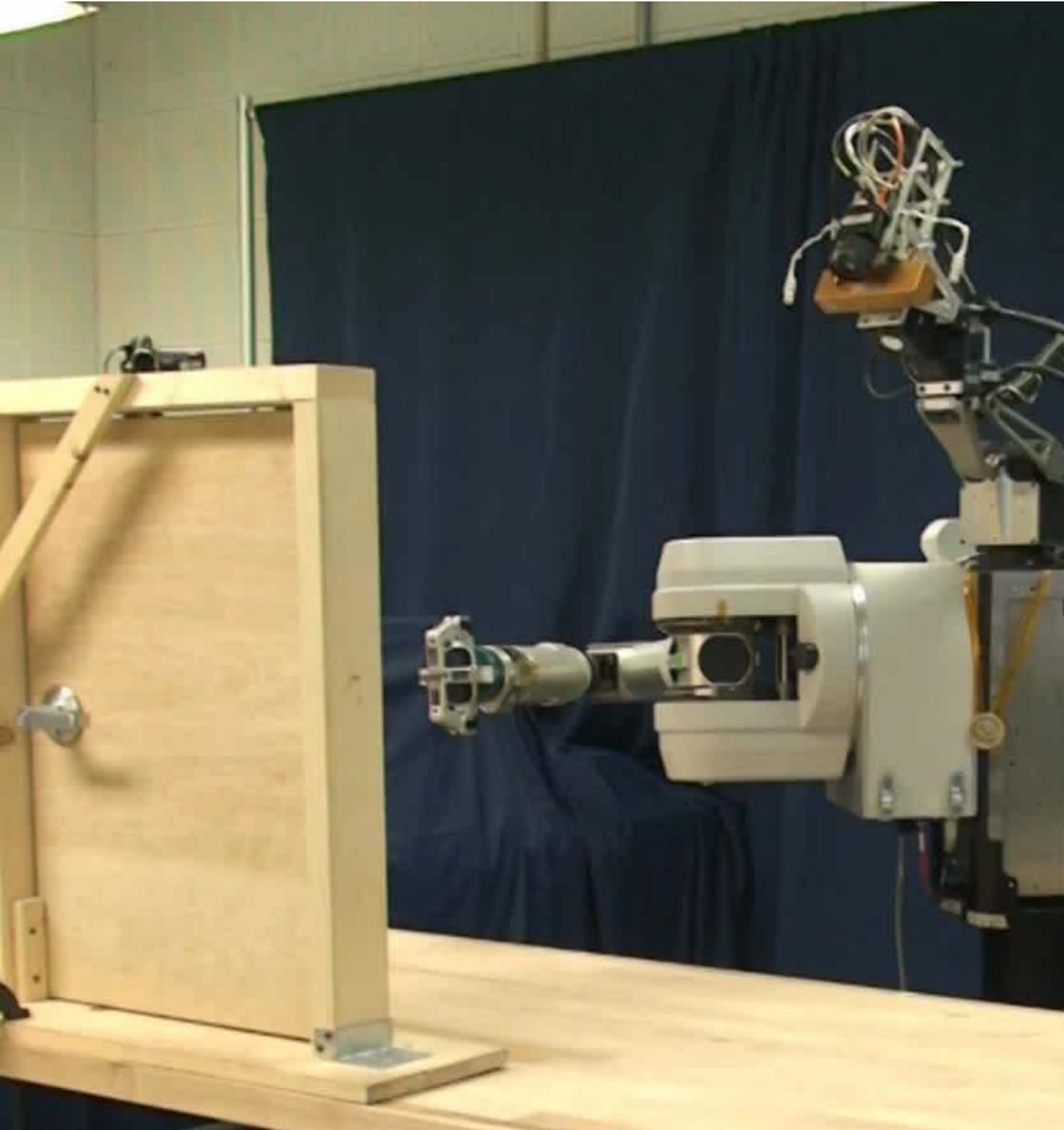
"Traditional" Sense-Plan-Act



DARPA ARM-S
AUTONOMOUS PICK AND PLACE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

NOVEMBER 15, 2011
2X REAL-TIME





DARPA ARM-S EXPERIMENTS UNLOCKING A DOOR

JET PROPULSION LABORATORY
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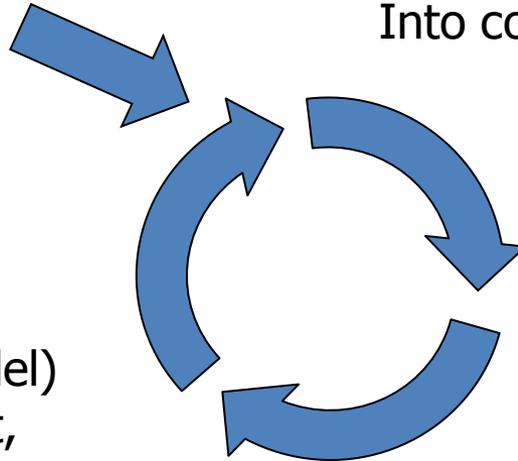
SEPTEMBER 22, 2011
2X REAL-TIME



Sense: Non-Contact Map building and initial object classification and localization

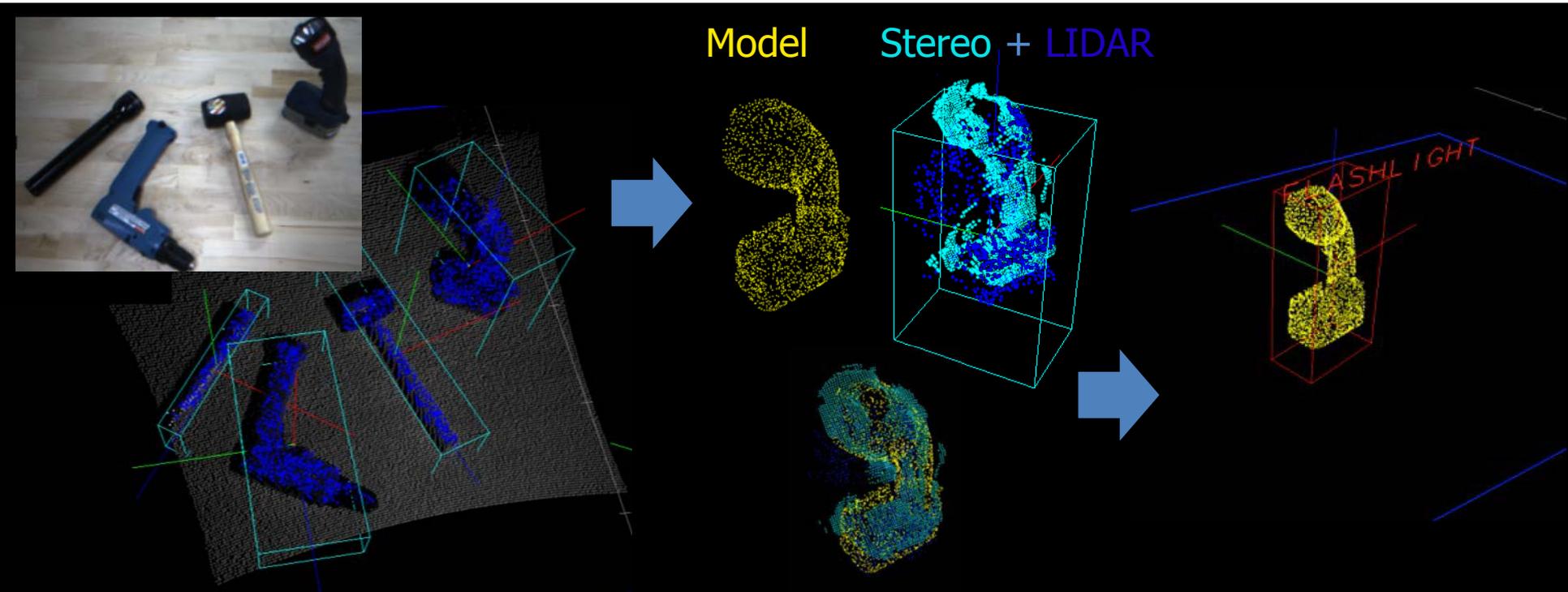
Plan (with best model)
Into contact with environment

Estimation
(conditioned on model)
Update object, robot, environment, contact states



Act/Control:
(feed-forward model)
Merge with feedback behaviors

- Minimal calibration: assume there are errors, and estimate online.
- Model Based: continual model refinement & use all aprori knowledge
- By the final DARPA test we had enforced touching (table or object), updating, and *then* grasping or manipulating, *for everything*



1. Table plane estimation (RANSAC)

2. 2.5 D map generation with clustering of elevated cells

3. Object Segmentation:

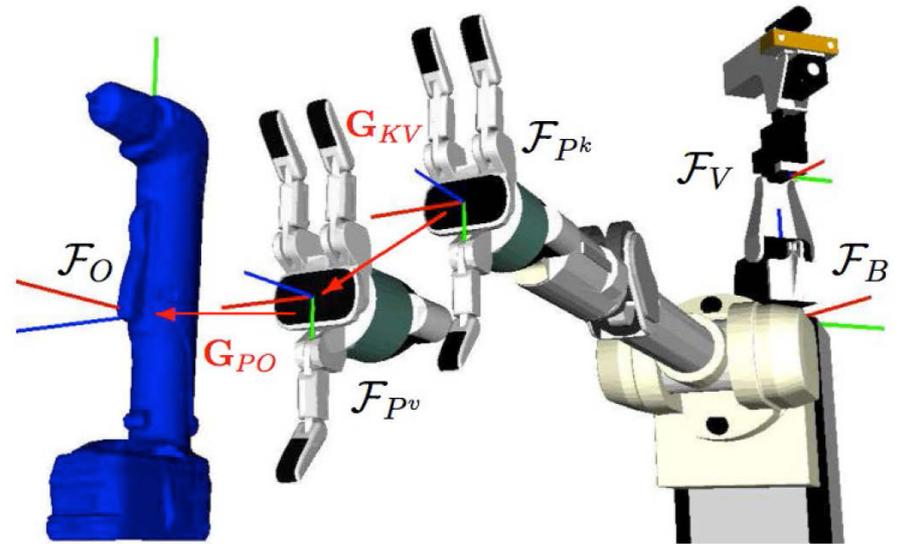
- a) Geometric/Volume Based
- b) Contour Based
- c) Color Based

Iterative Closed Point (ICP) pose refinement

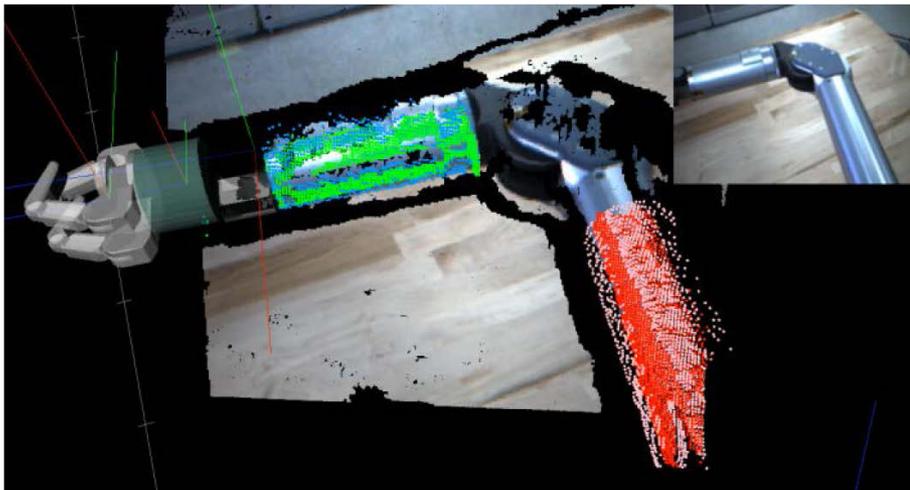
Contour and RGB space template matching

6 DOF Pose

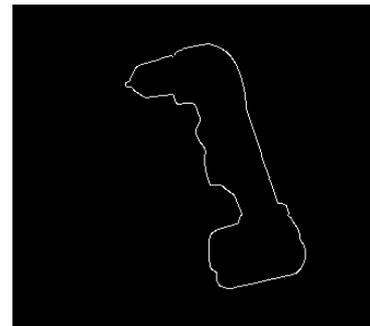
- Unscented Kalman Filter
- Measurement Fusion:
 - Visual (3D points, features, shape, silhouette)
 - Tactile (contact points)
 - Force Torque (object mass)
- State $X = \{G_{KV}, G_{PO}\}$



G_{KV} : Kinematic wrist to wrist in visual frame

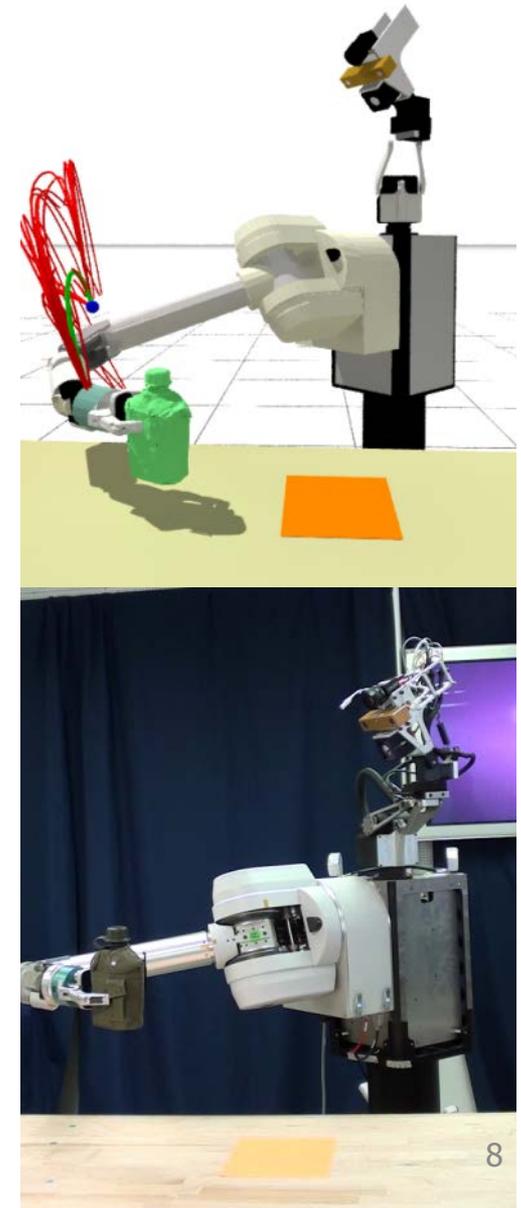


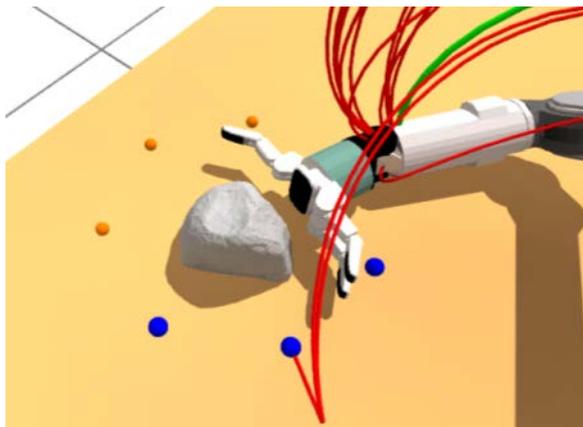
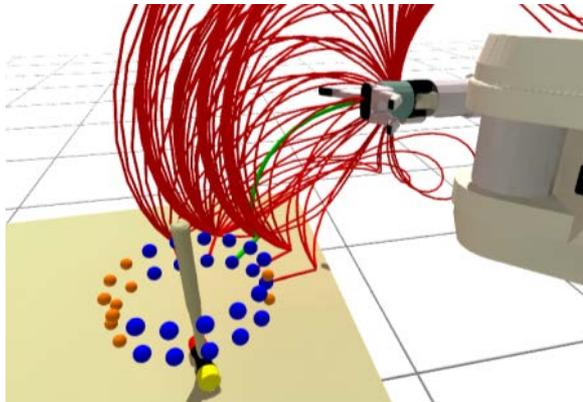
G_{PO} : Palm to Object



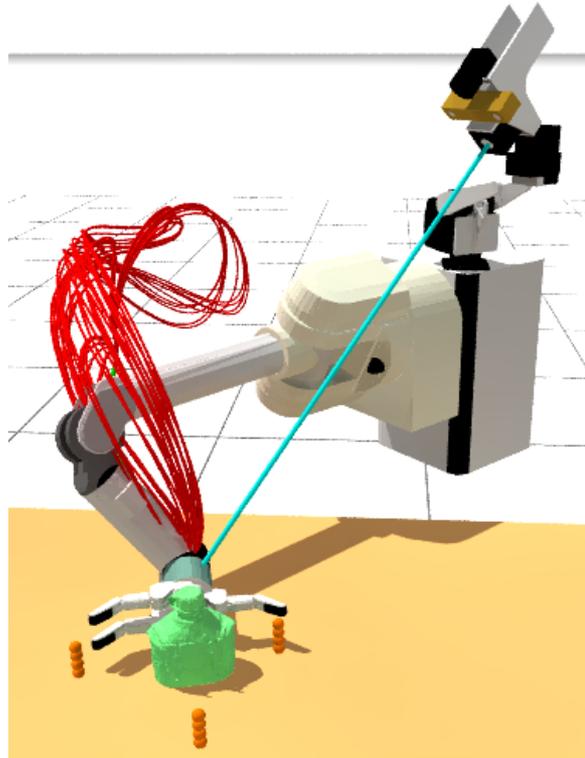
P. Hebert. *Combined Shape, Appearance and Silhouette for Simultaneous Manipulator and Object Tracking*. ICRA 2012
 TODAY 11:45-12:00 Room 3

- World modeling (robot + objects), using Spatial Operator Algebra (SOA) models
A. Jain, et al. Minimal Coordinate Formulation of Contact Dynamics in Operational Space. RSS 2012 (To Appear).
- Real-time estimation of object & arm pose conditioned on object models.
- Model-predictive trajectory planner for a 15-DOF robotic torso
 - Sampling in a lower DOF space of synchronized parameterized actions with bounded velocity constraints
 - Resulting motions are naturally continuous in velocity and do not require post-processing (smoothing).
 - Computationally efficient, parallelizable sampling methods.
T.M. Howard, et al. State Space Sampling of Feasible Motions for High Performance Mobile Robot Navigation in Complex Environments. JFR, Vol. 25, 2008.

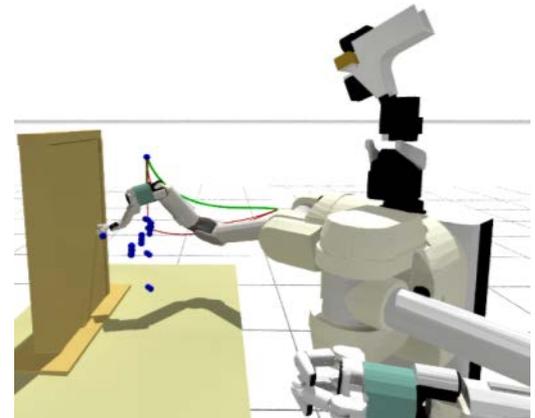
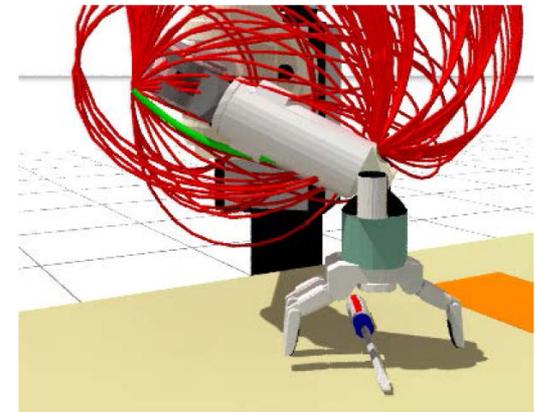




Grasping:
free-space or behavior-based for fully and partially known geometry

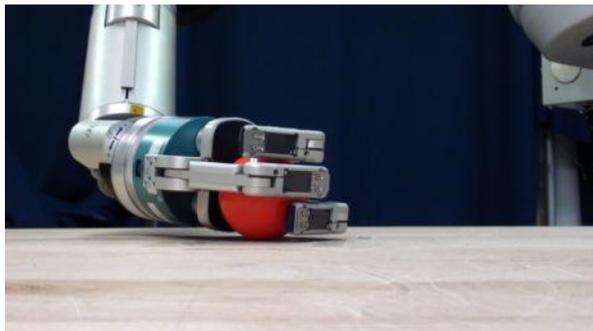
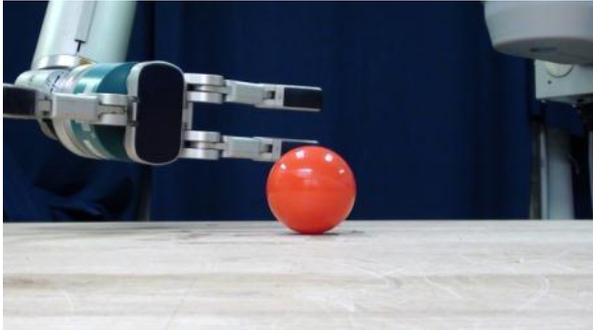


View planning:
minimize occlusions for arm tracking

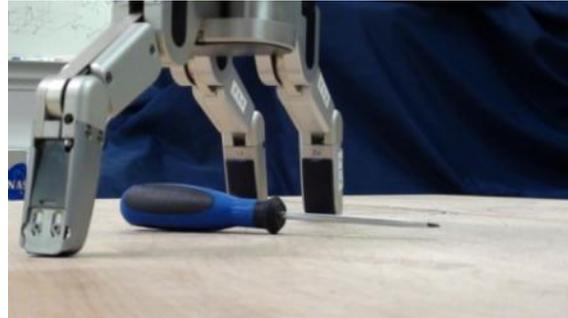


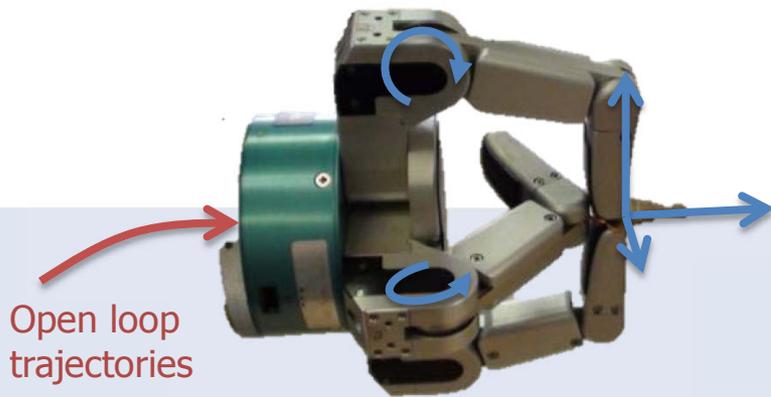
Interaction:
sequences of deliberate motion into objects and environment for localization

“grounding grasp”



“table grasp”



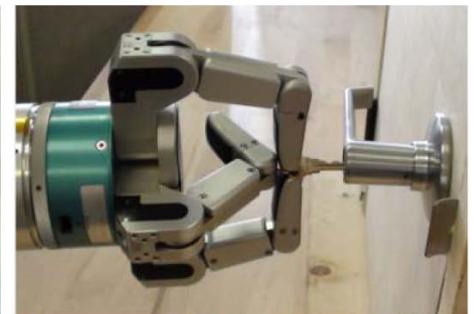
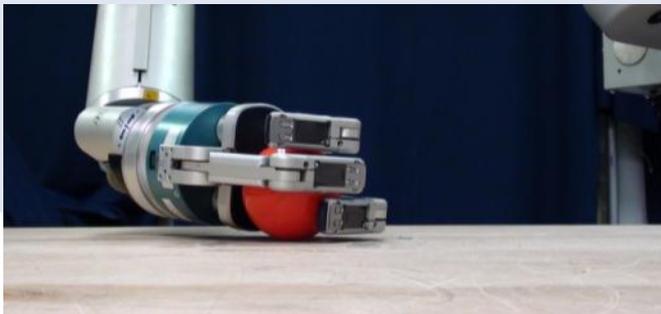


4 Task Frame Feedback Behaviors (Concurrent, Super-positioning) for all actions:

- Force-Torque Regularization
- Estimated Kinematic Wrist to Visual Wrist Feedback / Visual Tracking
- Dither additive disturbance
- Kinematic limit avoidance

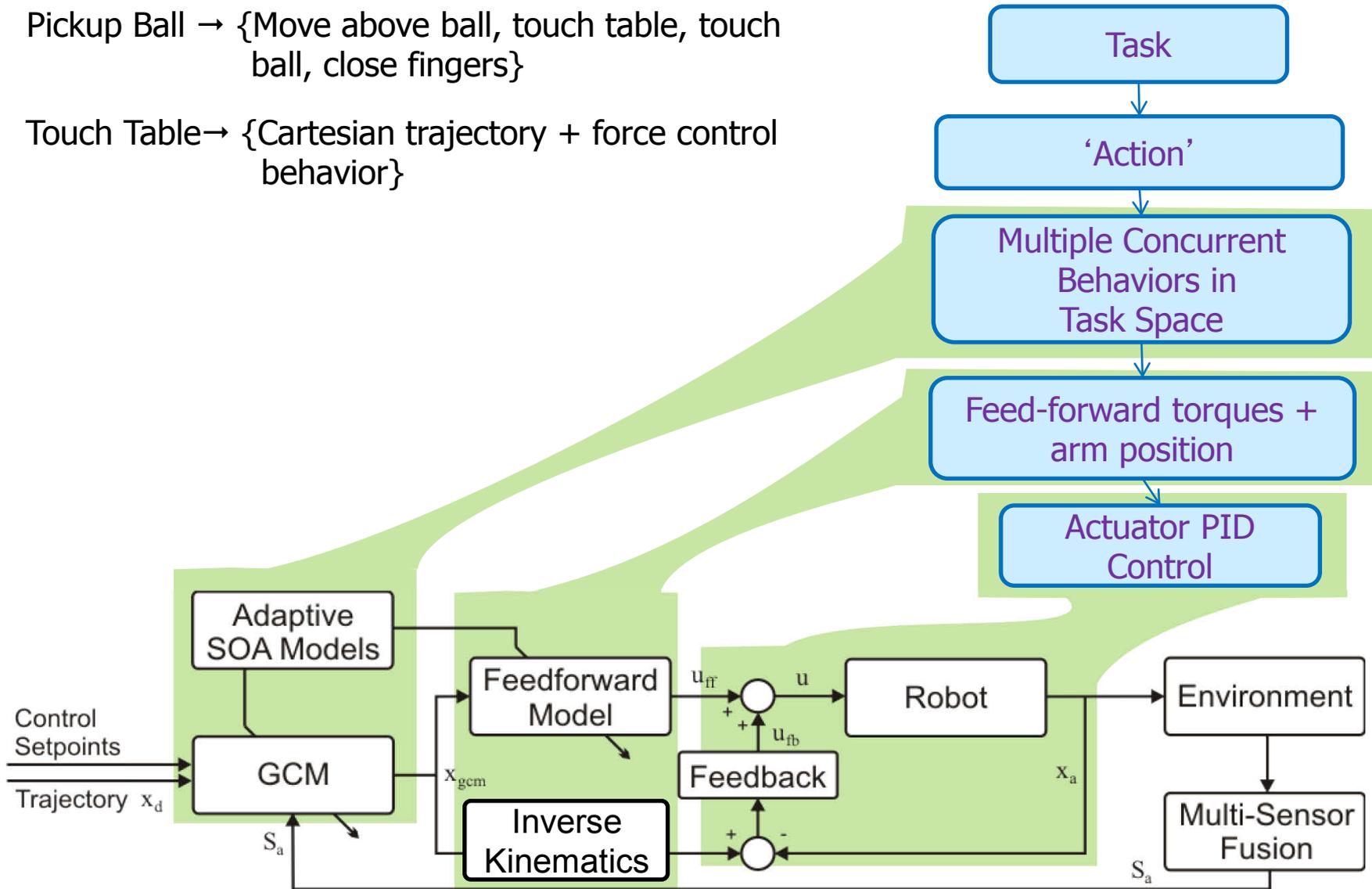
2 Finger Behaviors

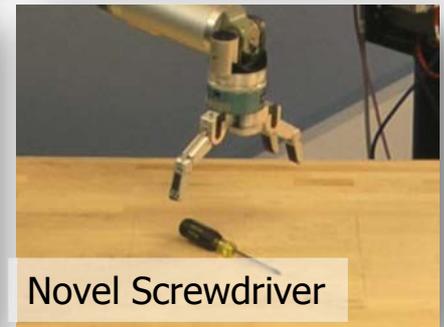
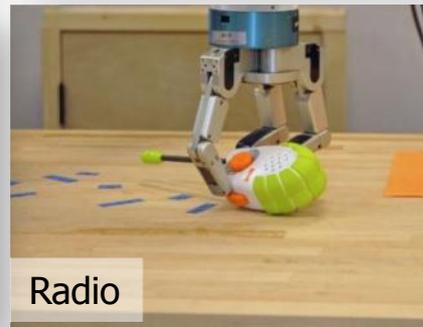
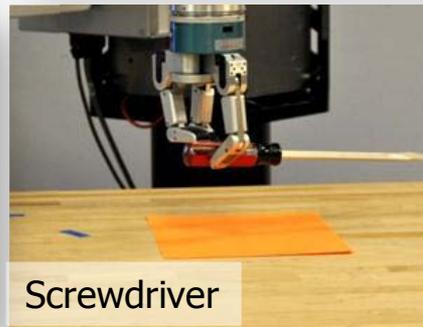
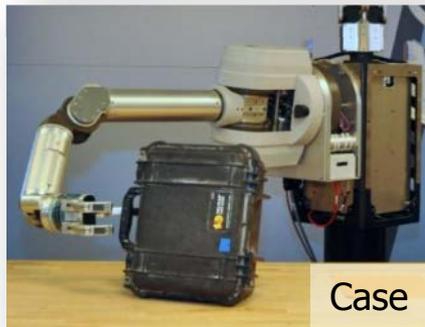
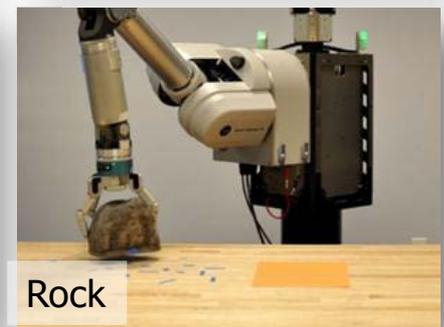
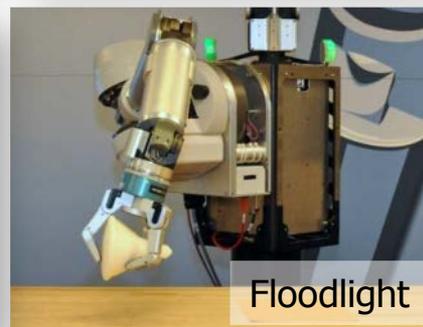
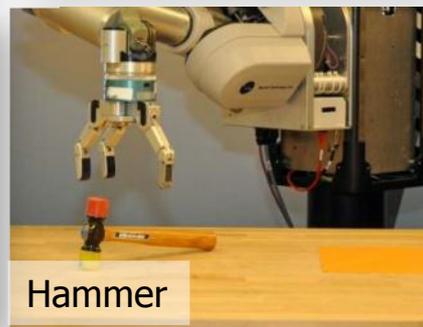
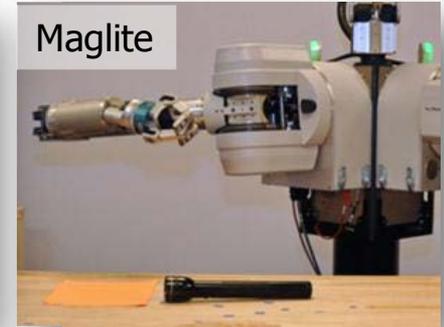
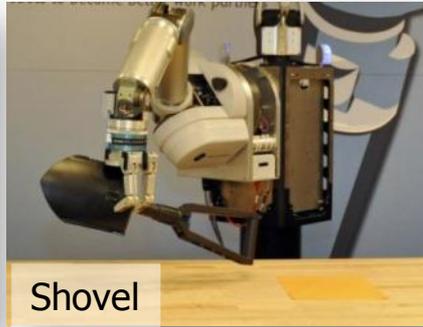
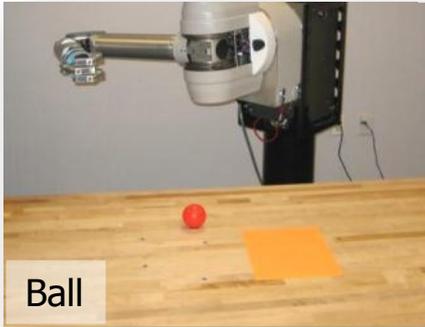
- Strain Regularization
- Pause on contact

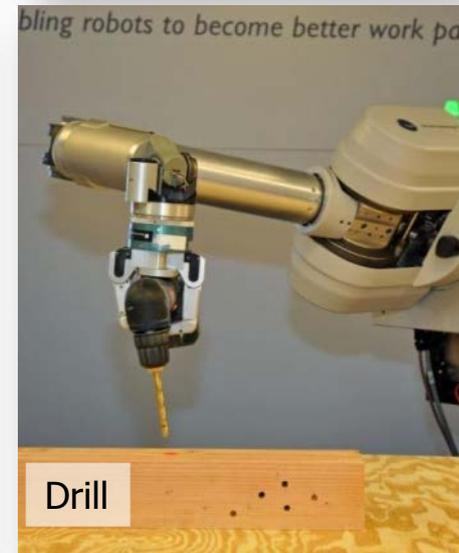
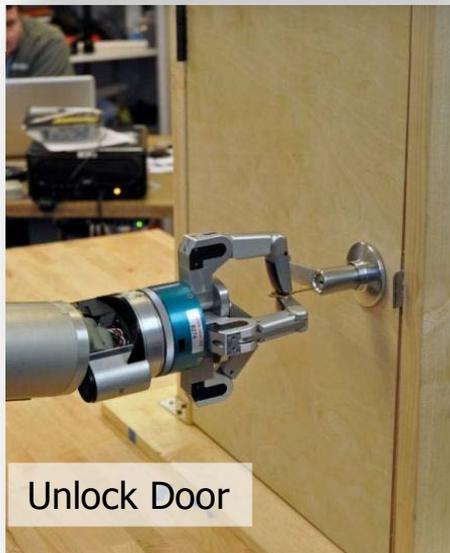
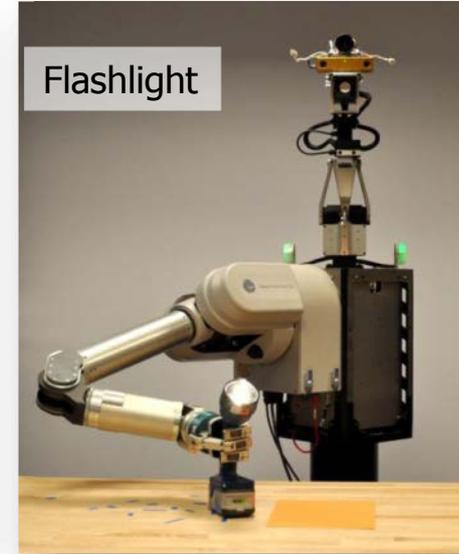
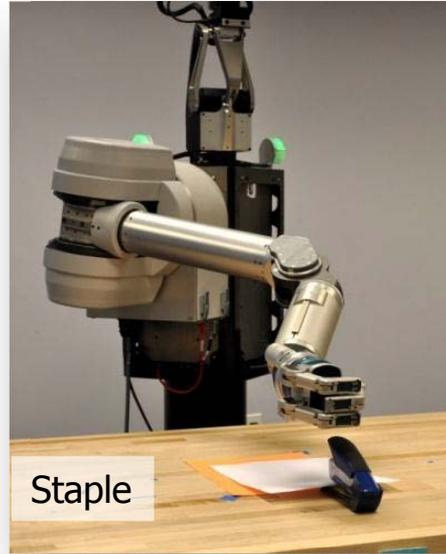
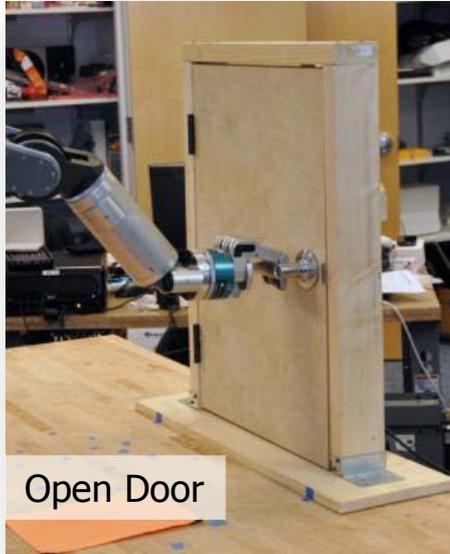


Pickup Ball → {Move above ball, touch table, touch ball, close fingers}

Touch Table → {Cartesian trajectory + force control behavior}









ARM-S Phase 1 Testing Results Table



JPL is "Team A"

	Successes (out of 72)	Grasping (out of 48)	Manipulation (out of 24)	Average Time (seconds)
JPL	67	47	20	75.4
Team B	67	47	20	80.6
Team C	64	46	18	77.5
Team D	58	47	11	125.7
Team E	58	41	17	170.7
Team F	49	42	7	151.8

Achieved with: Estimator/Model Based interactive manipulation

Questions?

For more info:

P. Hebert. *Combined Shape, Appearance and Silhouette for Simultaneous Manipulator and Object Tracking*. ICRA 2012

TODAY 11:45-12:00 Room 3

T. Allen. *Two-Fingered Caging of Polygons Via Contact-Space Graph Search*. ICRA 2012

Thursday 11:30-11:45 Room 2

ICRA May 16th 2012