

Lecture 08

Manipulation

New Frontiers



Image Credit - Boston Dynamics



Course Logistics

- **Quiz 6 was posted today and was due before the lecture.**
- Project 1 is posted on 09/20 and will be due 10/02 (today).
- Project 2 will be posted 10/02 (today) and will be due 10/11




Definition of Manipulation

Mason, Matthew T. "Toward robotic manipulation."
Annual Review of Control, Robotics, and Autonomous Systems 1 (2018): 1-28.

Carnegie Mellon University
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ABOUTPEOPLERESEARCHEDUCATIONNEWSEVENTSNREC

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Statement

Research

Publications

Students/Affiliates

I am **formally retired** at CMU, although still supervising students as they finish and graduate. Most of my activity has shifted to my position as Chief Scientist at Berkshire Grey.

I work in robotics.

The primary venue for my work is the **Manipulation Lab** (MLab).

ANNUAL
REVIEWS

Annual Review of Control, Robotics, and
Autonomous Systems

Toward Robotic Manipulation

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1:191-1924

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104848

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Keywords

robot, manipulation, evolution, engineering

Abstract

This article surveys manipulation, including both biological and robotic ma-
nipulation. Biology inspires robotics and demonstrates aspects of manipu-
lation that are far in the future of robotics. Robotics develops concepts and
principles that become evident only in the creative process. Robotics also
provides a test of our understanding. As Richard Feynman put it: "What I
cannot create, I do not understand."

This lecture uses the structure and material from this review paper!



Definition of Manipulation

Very few definitions of manipulation appear in the robotics literature. A European research road map defined manipulation as “the function of utilising the characteristics of a grasped object to achieve a task” (1, p. 38). A NASA road-mapping effort yields the following: “Manipulation pertains to making an intentional change in the environment or to objects that are being manipulated” (2, p. 13). My own earlier attempt at defining manipulation was “using one’s hands to rearrange one’s environment” (3, p. 1). Rather than sorting the pros and cons of those definitions, let us apply the shotgun method and identify every approach that we can.

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Definition of Manipulation

Definition 1 (etymological). Manipulation refers to the activities performed by hands.

Definition 2 (genus/differentia, ends only). Manipulation is when an agent moves things other than itself.

Definition 3 (genus/differentia, ends and means). Manipulation is when an agent moves things other than itself through selective contact.

Definition 4 (bottom up). Manipulation is pick-and-place manipulation plus in-hand manipulation plus mechanical assembly plus. . . .

Definition 5. Manipulation refers to an agent's control of its environment through selective contact.

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Animal Manipulation



Animal Manipulation



Smaller-scale manipulation exhibited by flagella and cilia
starting billion years ago

<https://makeagif.com/gif/flagella-cilia-VjpqAa>

Animal Manipulation

“The brain of an ant is one of the most marvellous atoms of matter in the world, perhaps more marvellous than the brain of man.” - Darwin



Intermediate-scale Manipulation Weaver ants ~20 million years ago

https://www.youtube.com/watch?v=1pkjpC4O_TM

Animal Manipulation

Intermediate-scale Manipulation Dung Beetle

Mobile Manipulation???



**Locomotion is a form of
manipulation??
Duality Principle**

<https://youtu.be/xNjymt6oCcQ>
<https://cdn2.vectorstock.com/i/1000x1000/53/51/big-dung-beetle-that-pushes-dirty-ball-vector-19965351.jpg>
https://t3.ftcdn.net/jpg/01/62/59/04/360_F_162590489_5lcesYmIOK0RC4T4r5lydft8aQmpCwI7.jpg

Animal Manipulation

Large-scale Manipulation using Tool - Chimpanzee



<https://www.youtube.com/watch?v=inFkERO30oM>

Animal Manipulation



<https://www.youtube.com/watch?v=YePKbjODrto>

Animal Manipulation



<https://www.youtube.com/watch?v=BXi3xJriGZY>

Animal Manipulation



<https://gifdb.com/images/high/insect-fly-rubbing-hands-tnpegh6d412vjafu.gif>

Human Manipulation



https://media.cnn.com/api/v1/images/stellar/prod/210807101343-restricted-01-neeraj-chopra-olympics-08-07-2021.jpg?q=w_2953,h_1984,x_0,y_0,c_fill

<https://www.espn.com/photo/shoib-akhtar-in-action-against-bangladesh-309353?objectId=306979>

https://media.gq.com/photos/5e30a0329d87db000817865a/master/w_1600%2Cc_limit/03-how-kobe-bryant-changed-sneaker-history-gq-january-2020.jpg



Human Manipulation



https://live.staticflickr.com/6086/6098540957_6bfd63d5d1_b.jpg



<https://qph.cf2.quoracdn.net/main-qimg-3252de8ffb3474dd57f5a534d343a7c3-lq>

Human Manipulation



Figure 2

Examples of human manipulation. (a) Throwing a baseball. (b) Knapping a stone tool. (c) Folding origami. (d) Cutting a potato. (e) Bimanual manipulation of a potato while the knife is parked in an ulnar grasp. (f) Pushing potato slices with a knife and spread fingers. Panel a from video (<https://youtu.be/jZKvjY6gDfg>) by Power Drive Performance (<http://www.pitcherspowerdrive.com>), reproduced with permission. Panel b by Helen Beare (<https://australianmuseum.net.au/image/stone-tools-initial-reduction-flaking>), reproduced with permission from the Australian Museum. Panel c from video by YouTube user kiwiwhispers ASMR (<https://youtu.be/SNfLEnnP6Nc>), reproduced with permission. Panels d-f adapted from frames of *The French Chef* (28).

Figure from - Mason, Matthew T. "Toward robotic manipulation." *Annual Review of Control, Robotics, and Autonomous Systems* 1 (2018): 1-28.

Elements of Robotic Manipulation

- Programmed Motion
- Compliant Motion
- Structured pick-and-place manipulation
- Unstructured pick-and-place manipulation
 - Path planning
 - General-purpose grippers
 - Grasp and placement pose planning
- Assembly and task mechanics
- In-hand Manipulation
- Nonprehensile Manipulation
- Whole-X Manipulation



Programmed Motion

- Rests on the developments in motors, transmissions, encoders, kinematics, mechanism design, dynamic modeling and control



<https://www.therobotreport.com/wp-content/uploads/2023/03/kuka-robots-cars.jpg>



Compliant Motion

- Context of teleoperation
- Hybrid-position/force control
- Impedance control



<https://www.youtube.com/watch?app=desktop&v=KU--TOMDDFU>

Structured pick-and-place manipulation

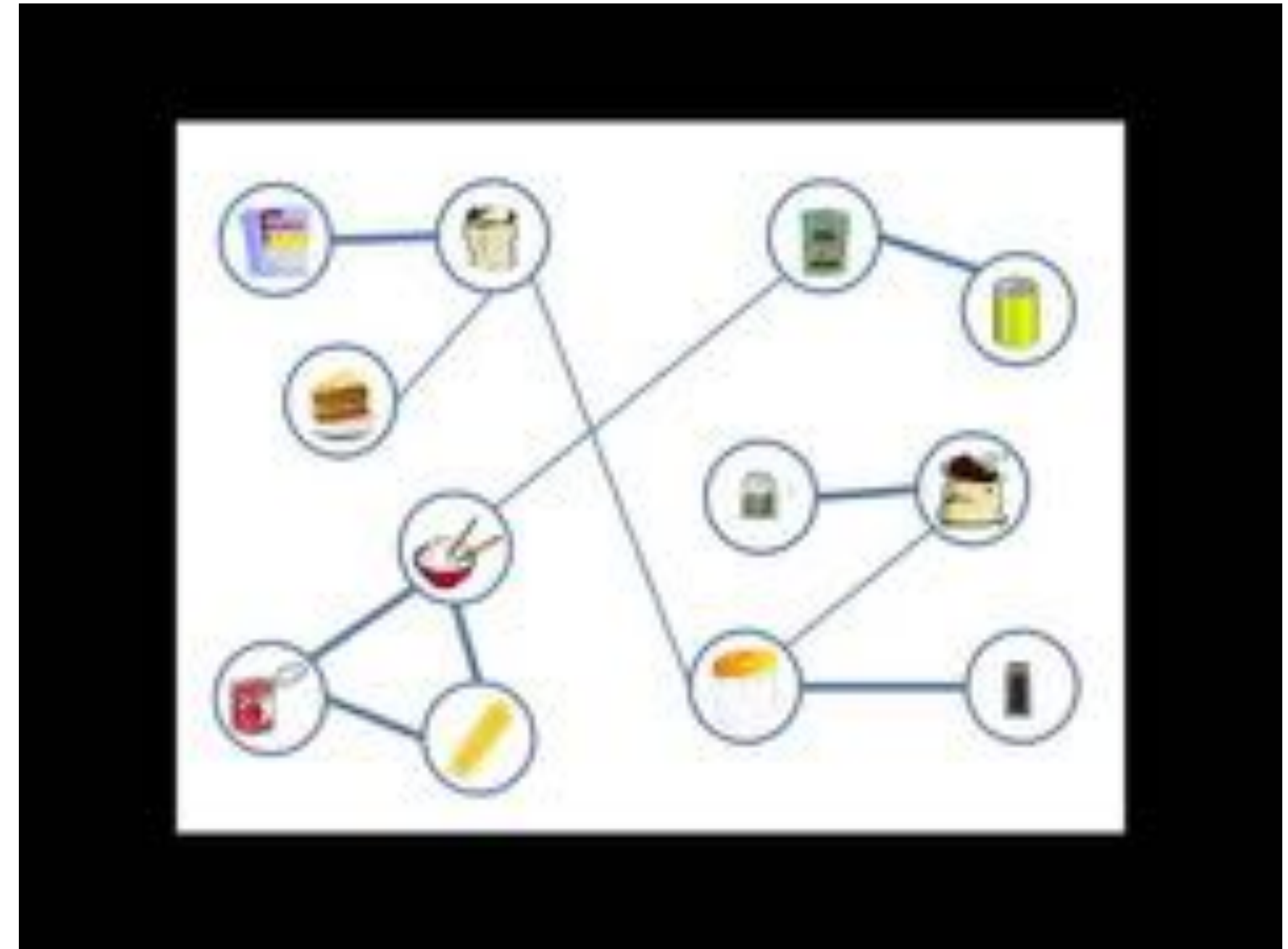
- Moving a sequence of objects one at a time from one place to another.
- Structured environment and scenario
 - Objects are identical
 - Motion is repetitive
 - Gripper design and motion programming is done offline.



<https://youtu.be/wg8YYuLLoM0?feature=shared&t=80>

Unstructured pick-and-place manipulation

- Planning software to produce arm motions
- Grippers that can handle a broad range of objects
- Grasp pose planning
- Stable placement pose planning

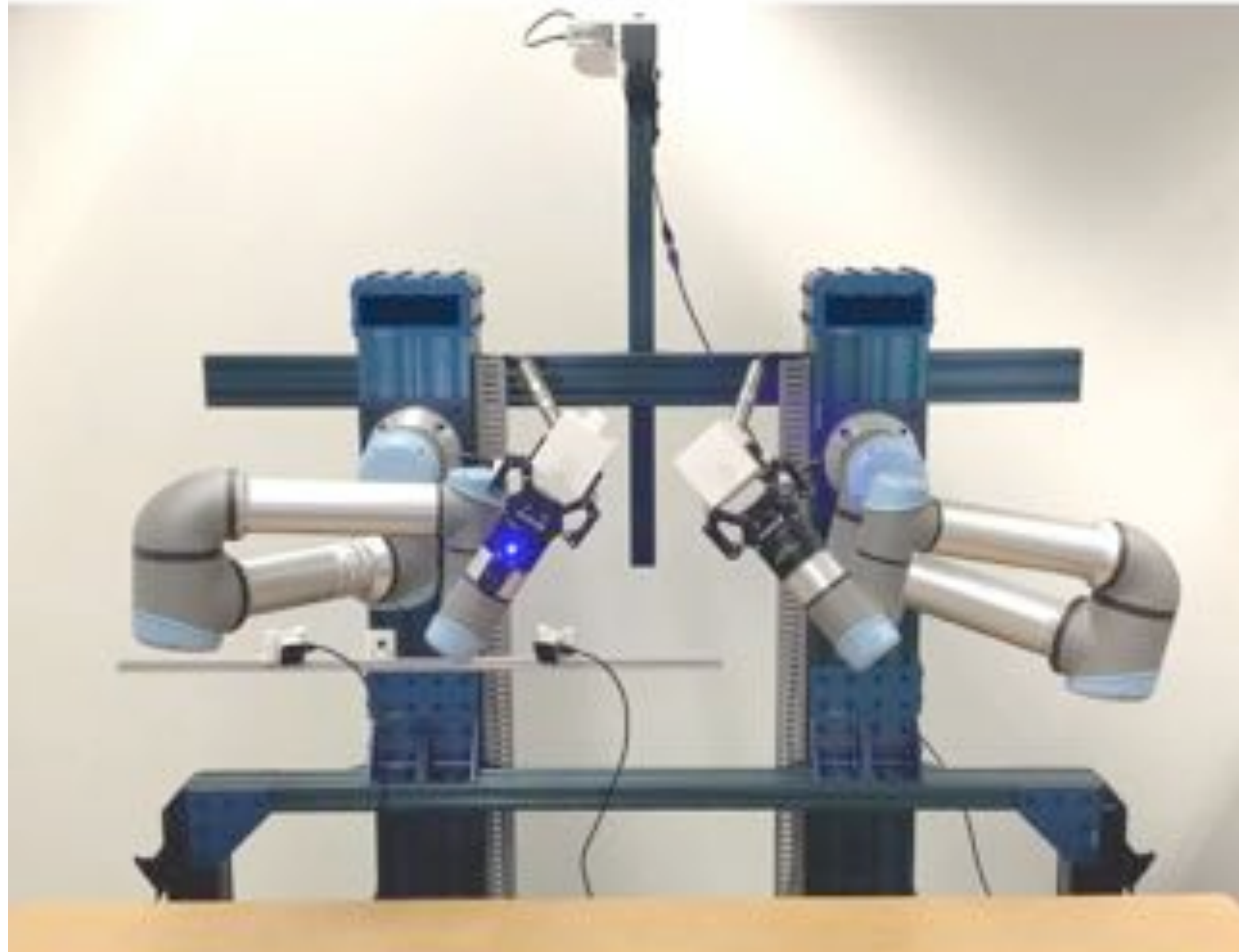


Abdo, Nichola, Cyrill Stachniss, Luciano Spinello, and Wolfram Burgard. "Organizing objects by predicting user preferences through collaborative filtering." *The International Journal of Robotics Research* 35, no. 13 (2016): 1587-1608.

https://www.youtube.com/watch?app=desktop&v=_icB8QcycMM

Robotic Assembly Task

Task: Geometry Informed Object Assembly



Ku et al. under review

In-hand Manipulation



Chen, Tao, Jie Xu, and Pulkit Agrawal. "A system for general in-hand object re-orientation." In *Conference on Robot Learning*, pp. 297-307. PMLR, 2022.

Whole-body manipulation



Kindle, Julien, Fadri Furrer, Tonci Novkovic, Jen Jen Chung, Roland Siegwart, and Juan Nieto. "Whole-body control of a mobile manipulator using end-to-end reinforcement learning." *arXiv preprint arXiv:2003.02637* (2020).
<https://www.youtube.com/watch?v=3qobNCMUMV4>

Taxonomy of Grasps

		Power						Intermediate			Precision				
		Palm		Pad				Side			Pad				Side
Opp:	VF:	3-5	2-5	2	2-3	2-4	2-5	2	3	3-4	2	2-3	2-4	2-5	3
Thumb Abducted			1: Large Diameter	31: Ring	28: Sphere 3 Finger	18: Extension Type	19: Distal Type	23: Adduction Grip		21: Tripod Variation	9: Palmar Pinch	8: Prismatic 2 Finger	7: Prismatic 3 Finger	6: Prismatic 4 Finger	20: Writing Tripod
			2: Small Diameter			26: Sphere 4-Finger					24: Tip Pinch				
			3: Medium Wrap								33: Inferior Pincer	14: Tripod	27: Quadpod	12: Precision Disk	
			10: Power Disk											13: Precision Sphere	
			11: Power Sphere												
Thumb Adducted	17: Index Finger Extension							16: Lateral	25: Lateral Tripod						
			4: Adducted Thumb					29: Stick						22: Parallel Extension	
			5: Light Tool												
			15: Fixed Hook					32: Ventral							
			30: Palmar												

Fig. 4. GRASP taxonomy that incorporates all previous grasp classifications. The grasps are classified in the columns according to their assignment into power, intermediate and precision grasp, the opposition type, and the VF assignment. The assignment of the rows is done by the position of the thumb that can be in an abducted or adducted position.

Feix, Thomas, Javier Romero, Heinz-Bodo Schmiedmayer, Aaron M. Dollar, and Danica Kragic. "The grasp taxonomy of human grasp types." *IEEE Transactions on human-machine systems* 46, no. 1 (2015): 66-77.



Why is robot manipulation challenging?

- Mechanism
- Perception
- Modeling and Control
- Planning
- Uncertainty



Future research challenges

1. Is there a fundamental and precise metric for comparing manipulative behaviors, or for comparing tasks, that would provide a basis for measuring progress in the field?
2. How can we best take advantage of advances in machine learning to advance our understanding and improve our technology?
3. How do we develop the adaptability, robustness, and breadth of behaviors exhibited by animals and humans?

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Next lecture: Path Planning

