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.

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.

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

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

Animal Manipulation

Large-scale Manipulation using Tool - Chimpanzee

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

Animal Manipulation

Animal Manipulation

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

Animal Manipulation

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

Human Manipulation

Human Manipulation

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

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

Human Manipulation

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

- Impedence control

an "R"

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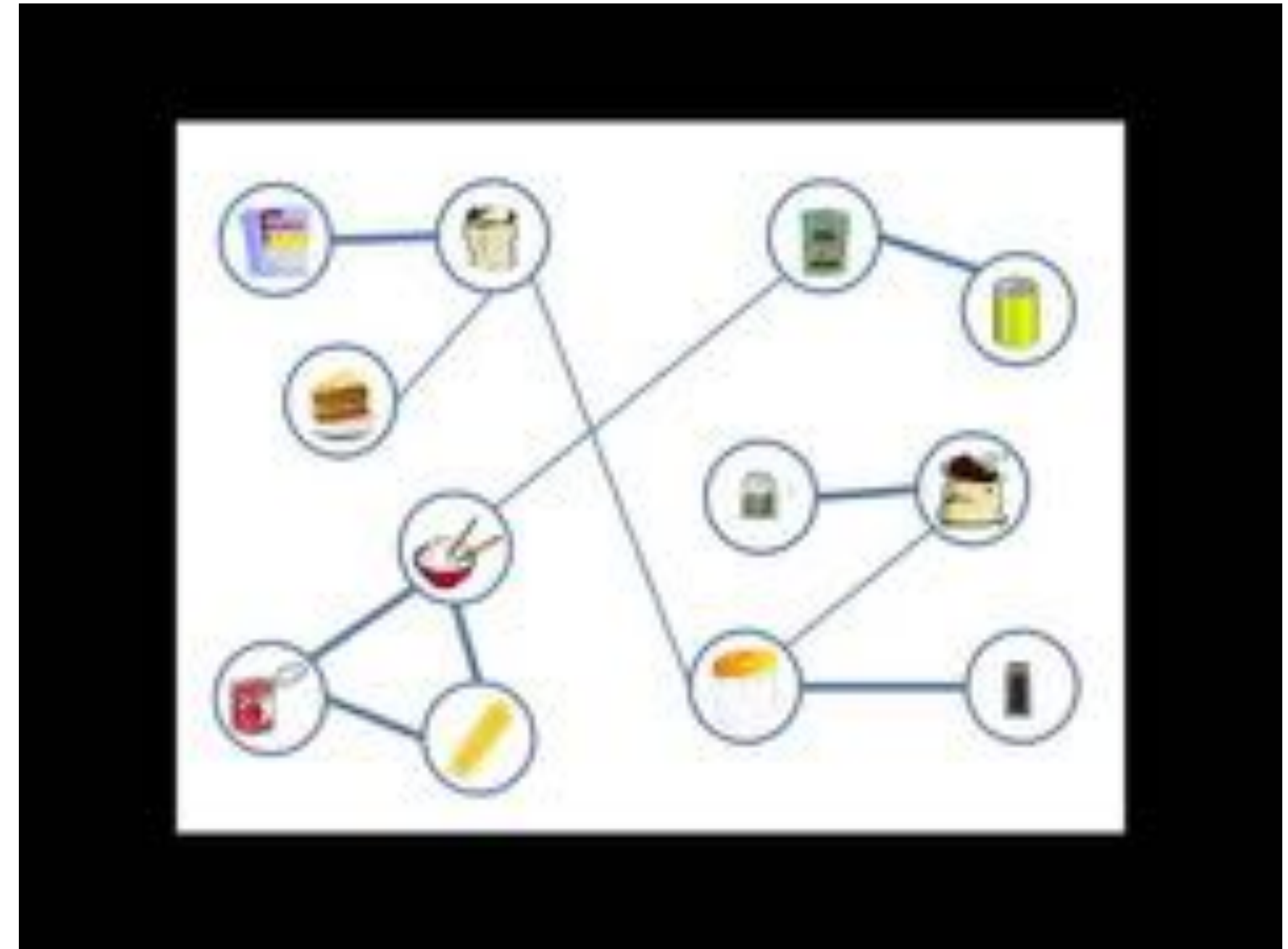
Abdo, Nichola, Cyrill Stachniss, Luciano Spinello, and Wolfram Burgard. "Organizing objects by predicting user preferences through collaborative filtering." *The International Journal of Robotics Research* 35, no. 13 (2016): 1587-1608.

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

Robotic Assembly Task

Task: Geometry Informed Object Assembly
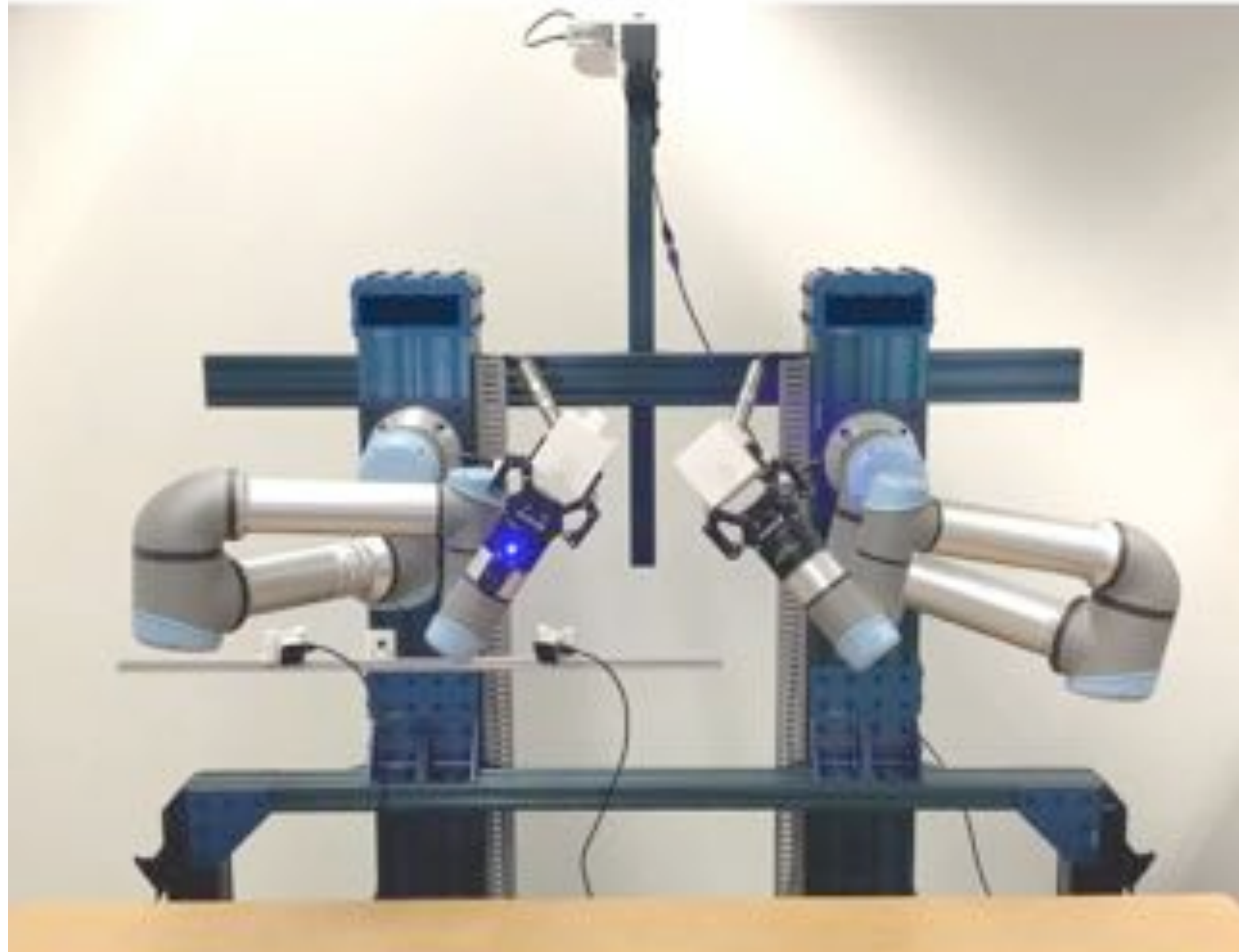
Ku et al. under review

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

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 be 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?

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

Next lecture:
Path Planning