

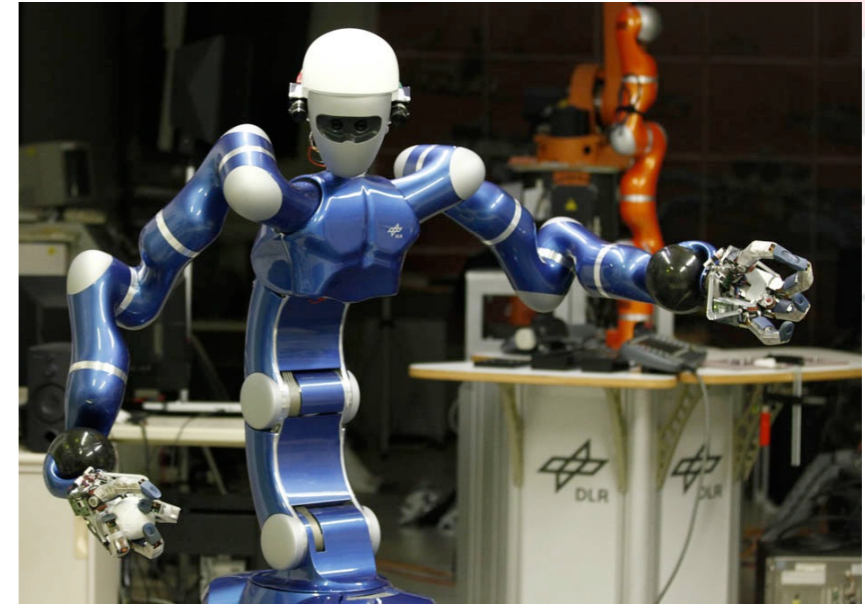
The background features a large, faint watermark of the Brown University crest. The crest includes a shield with a red cross, a sun with a face above it, and a banner at the bottom with the Latin motto "IN DEO SPERAMUS".

Robotics

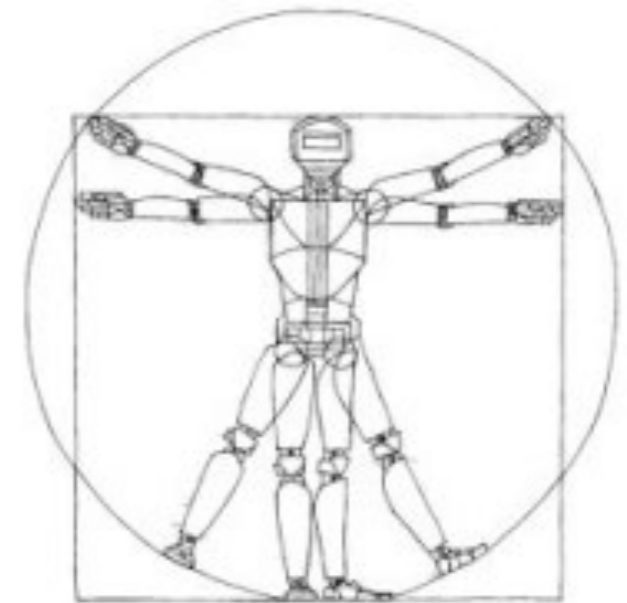
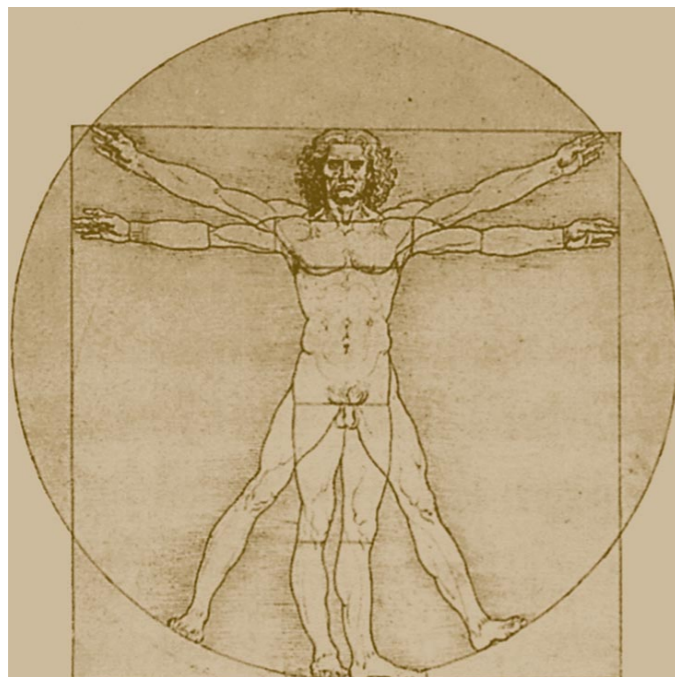
George Konidakis
gdk@cs.brown.edu

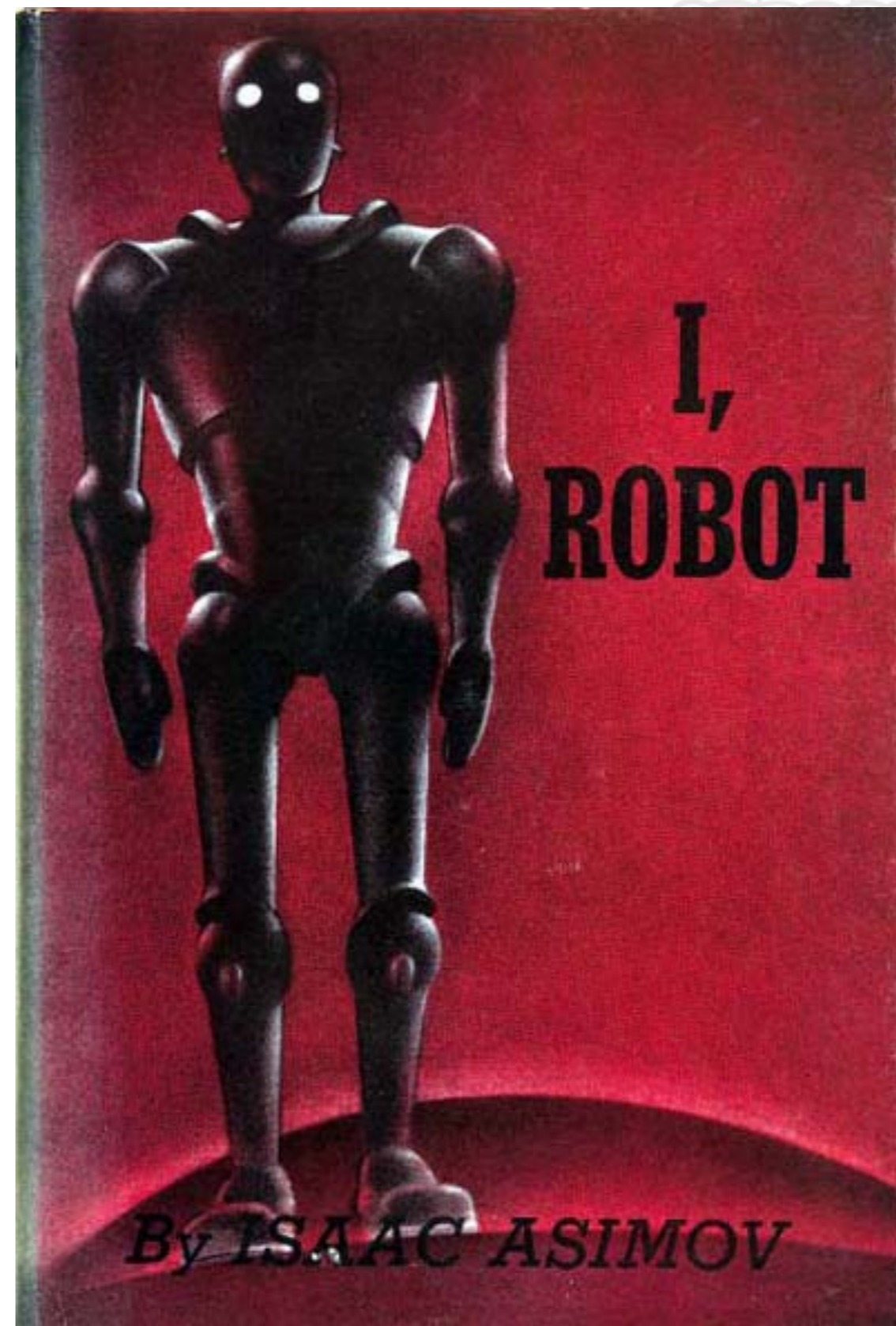
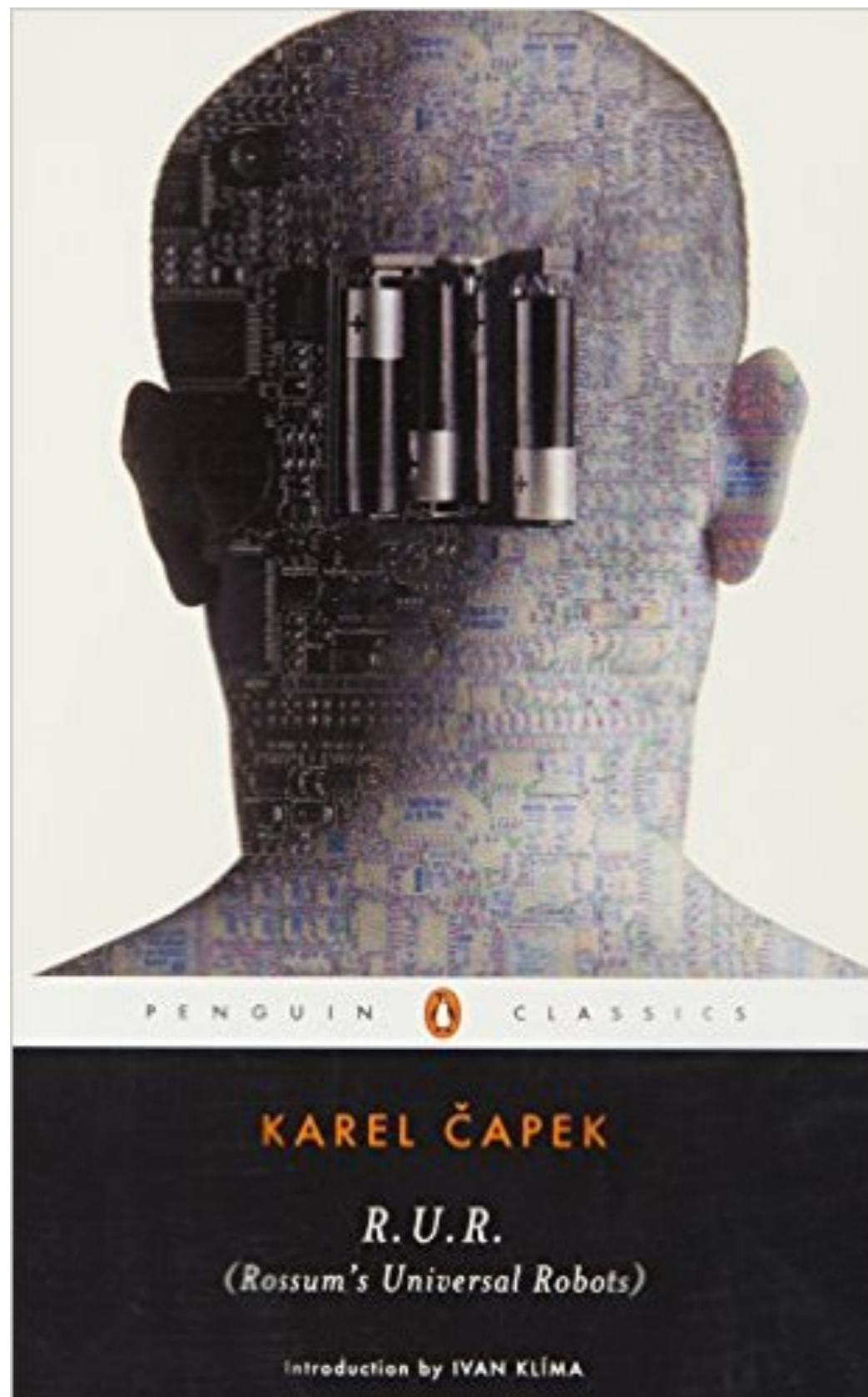
Fall 2021

Robots



Robotics as AI

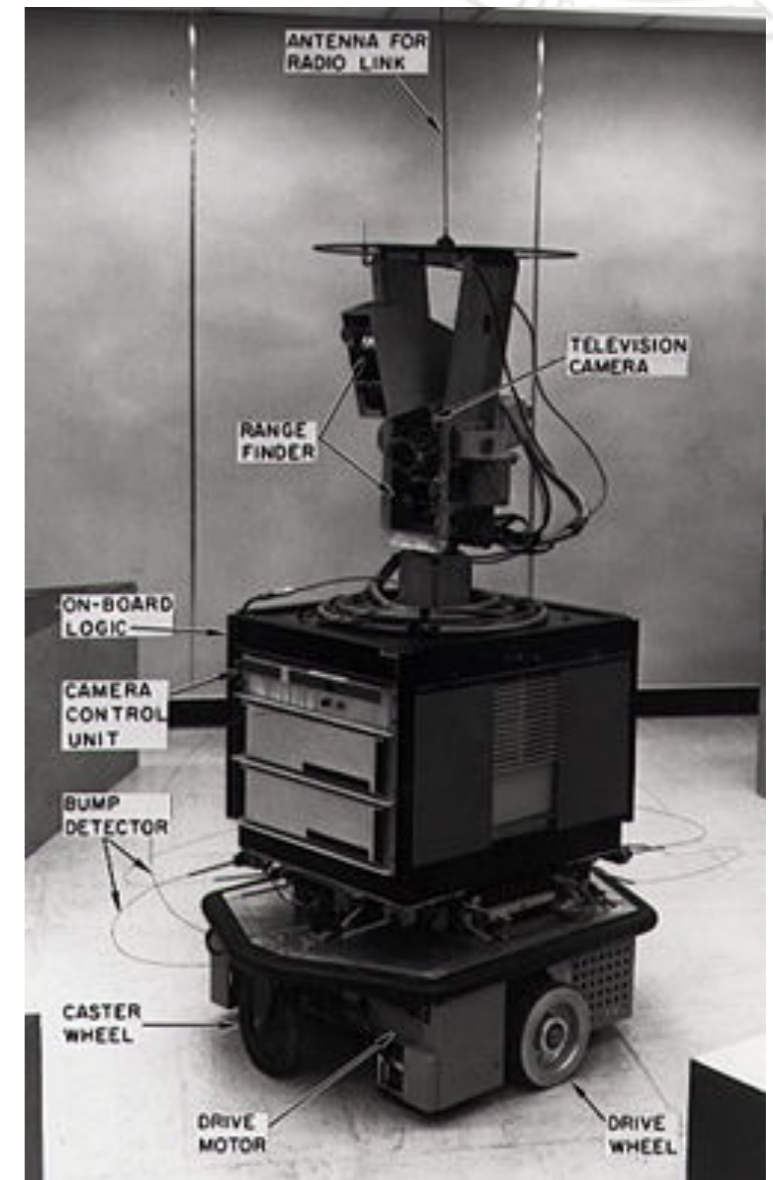




Robotics

Shakey the Robot 1966 - 1972

First robot to combine reasoning and low-level action, an attempt at a truly integrated and complete AI system.



Robotics

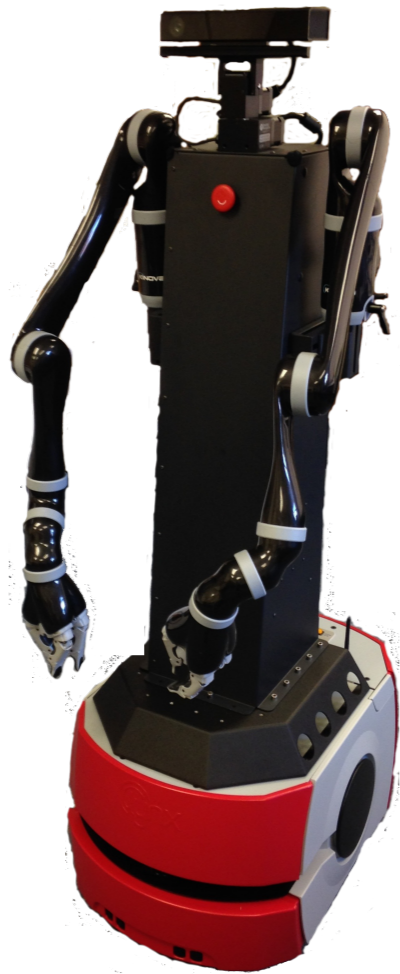
High-level Reasoning

Discrete, abstract, symbolic.

PourTea :

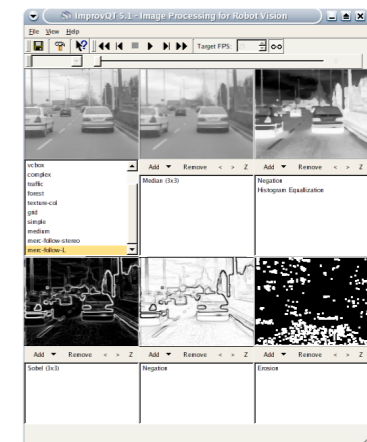
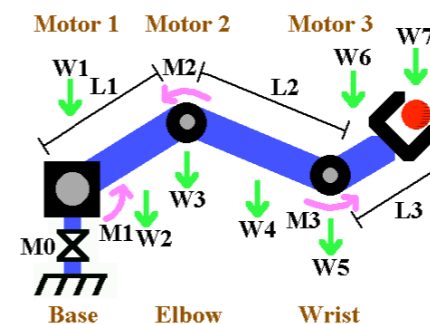
Pre : HoldingKettle \wedge KettleFull

Effect : \neg KettleFull \wedge TeaPoured



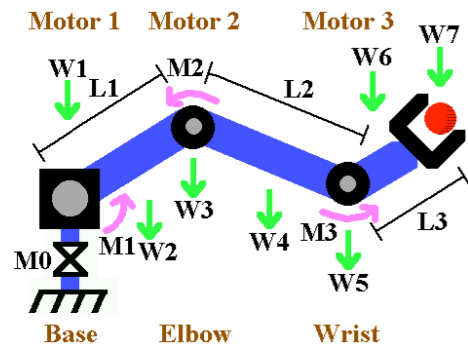
Continuous, noisy, locally and partially observable, sensorimotor space.

Low-level Control



Robotics

Low-Level



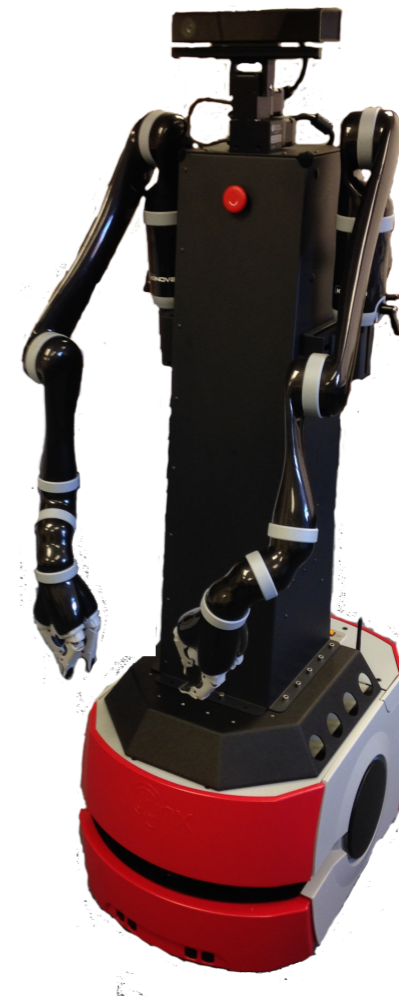
Mid-Level



High-Level

```
(:action pick_up2
:parameters ()
:precondition (and (symbol1) (symbol3)
                  (symbol5) (symbol6) (symbol11))
:effect (probabilistic
  0.0559 (and)
  0.9441 (and (symbol2) (not (symbol3))
             (decrease (reward) 53.42))
)
```

High-level Reasoning

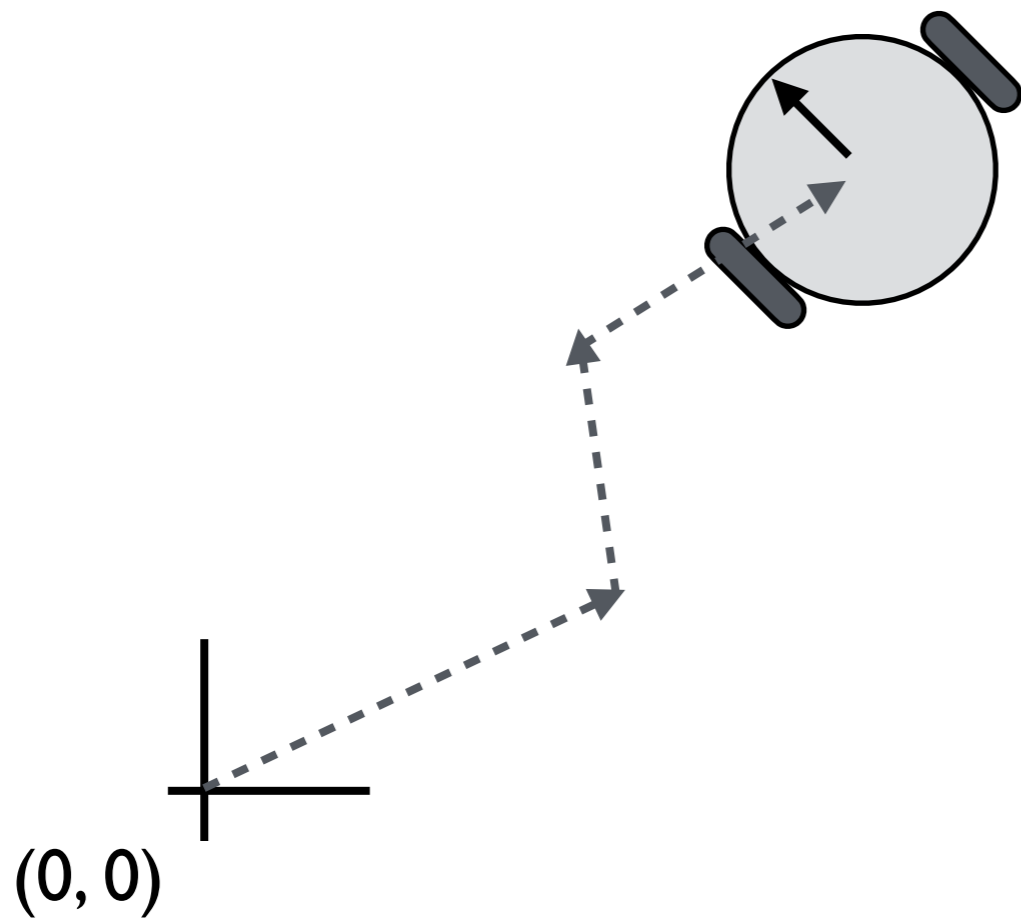


Low-level Control



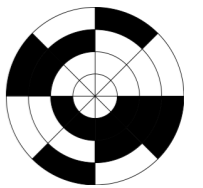
Kinematics

The first key question: where am I?



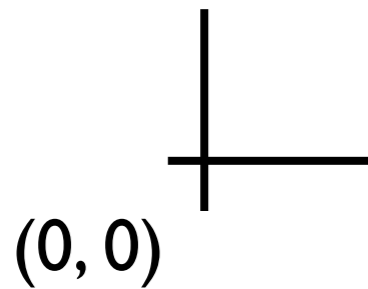
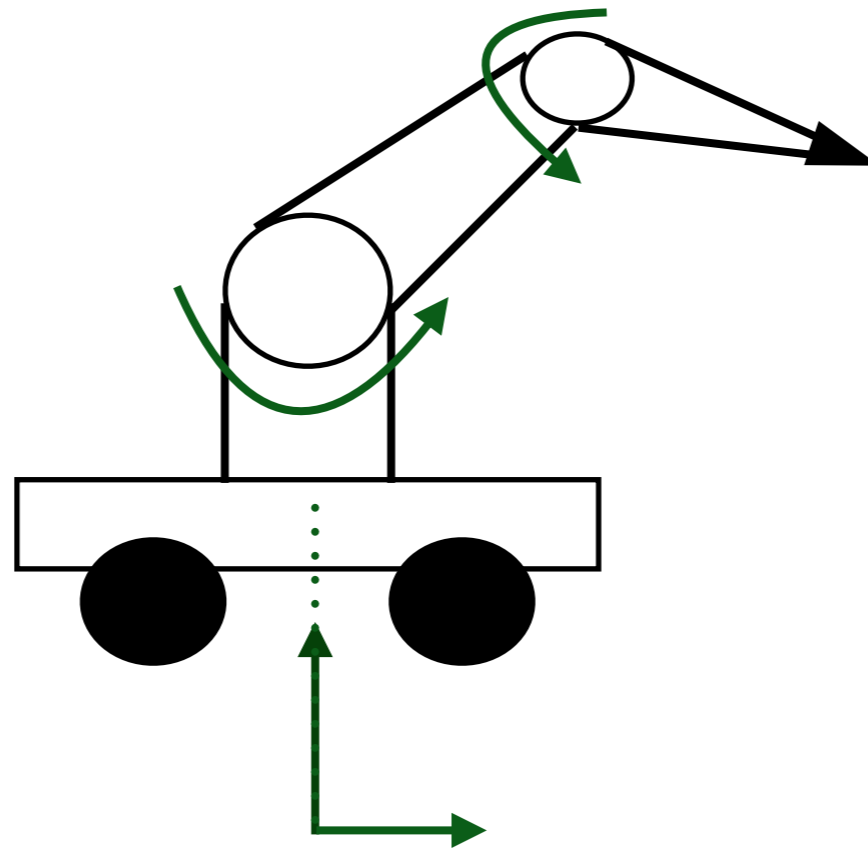
Relevant sensor:

Encoders



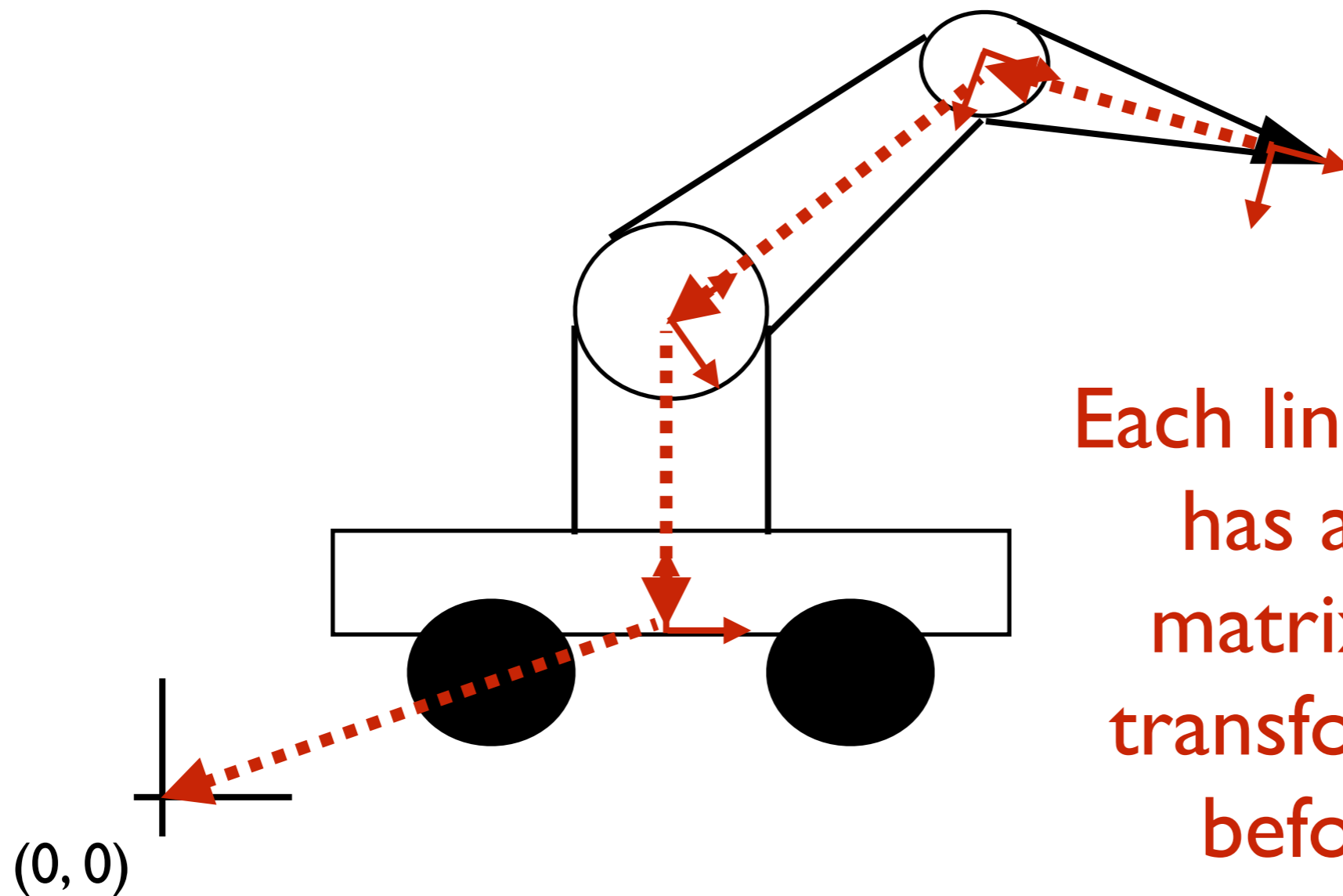
Kinematics

Where's my gripper?



Kinematics

Key idea: coordinate frame attached to rigid link.



Each link in the series has a transform matrix describing transform from link before it to its own coordinate frame

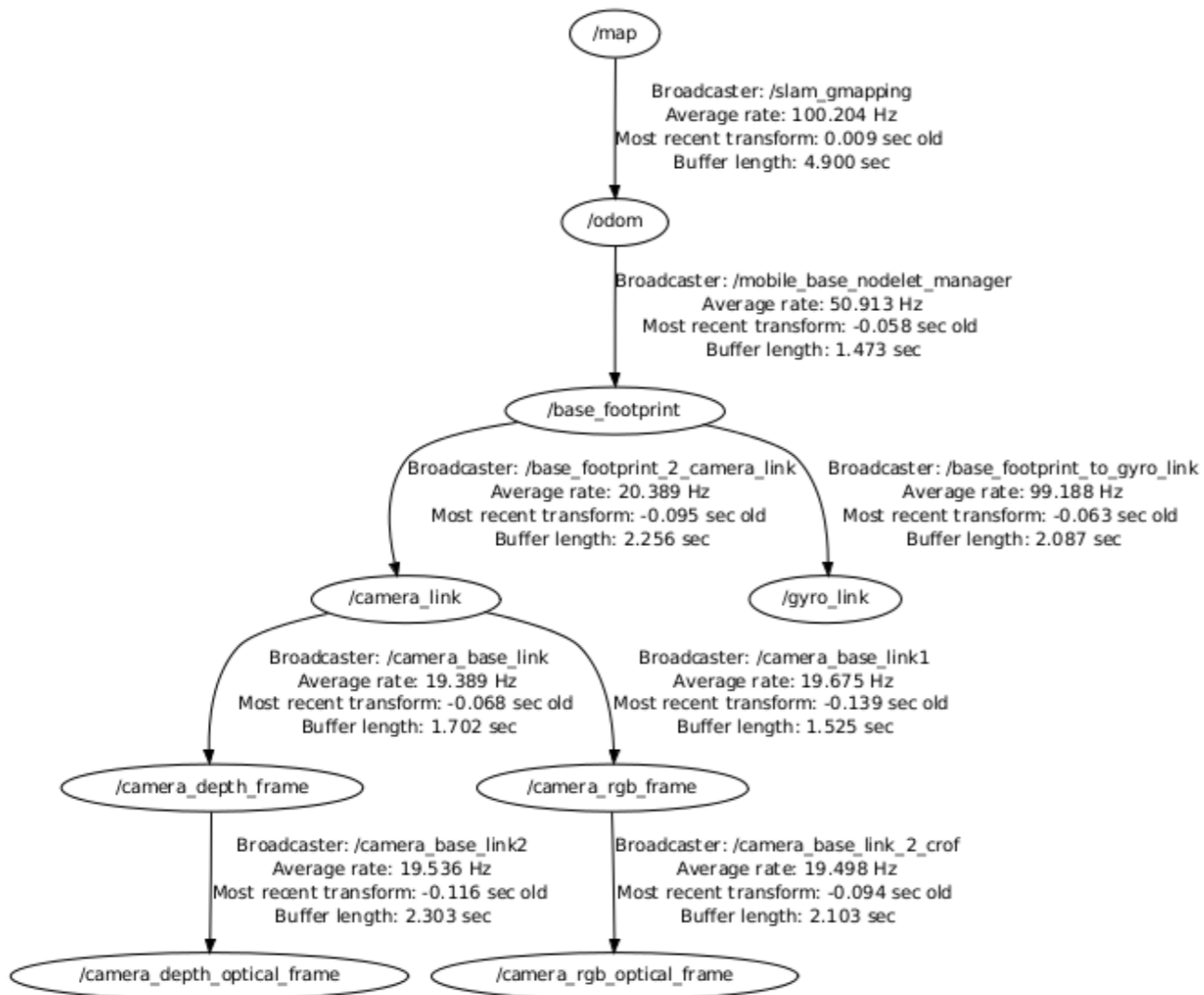
Registering Sensor Data

Data given in the coordinate frame of the sensor.



Kinematics

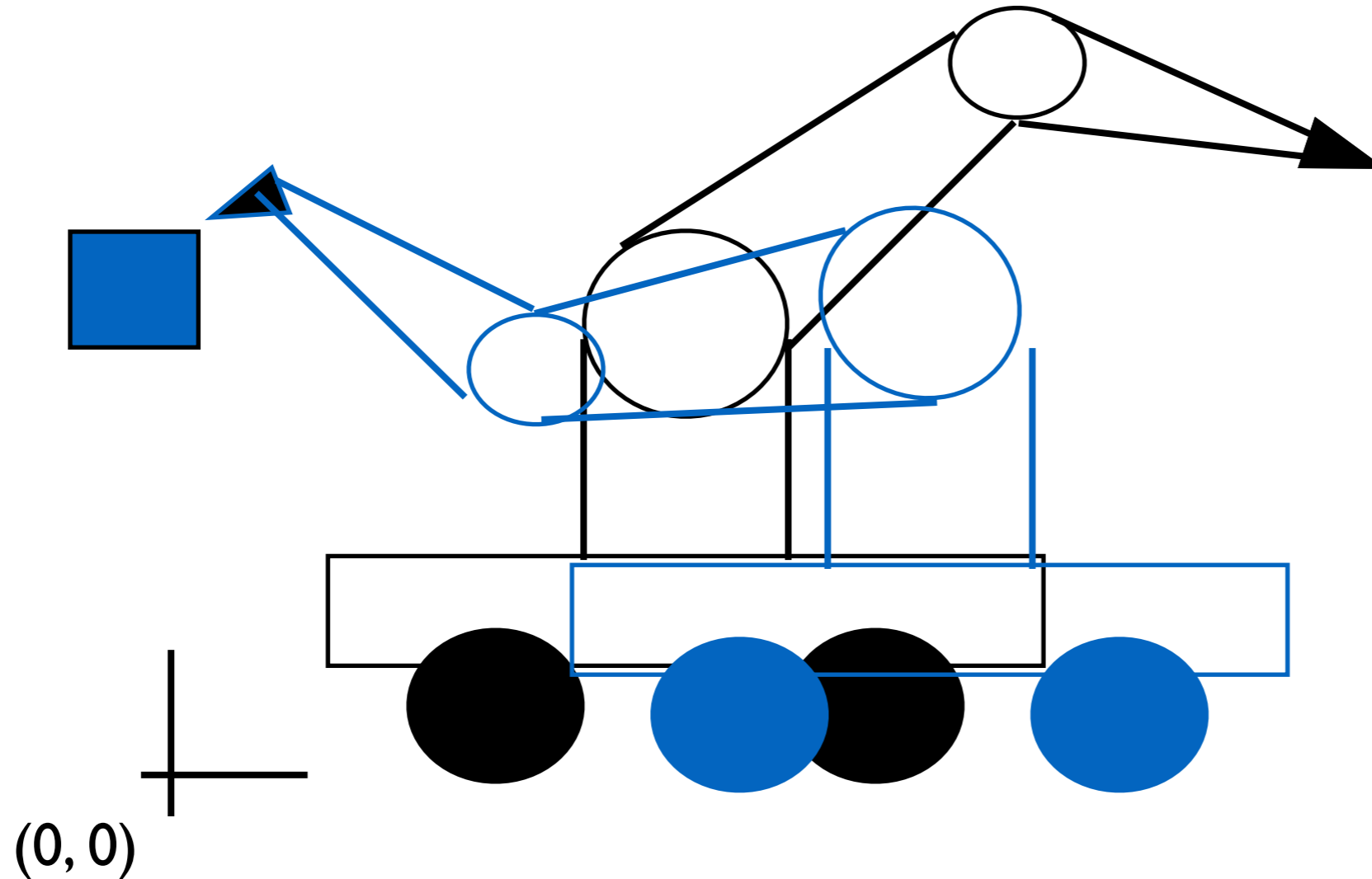
Matrices linked together in a tree



Inverse Kinematics

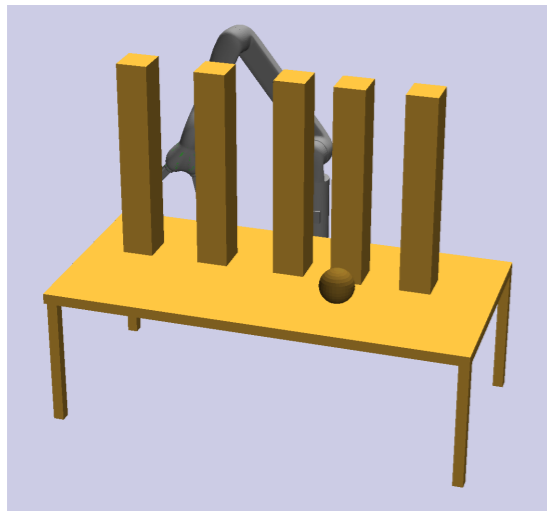
The reverse question.

Given a target pose in world-space, what joint values reach it?

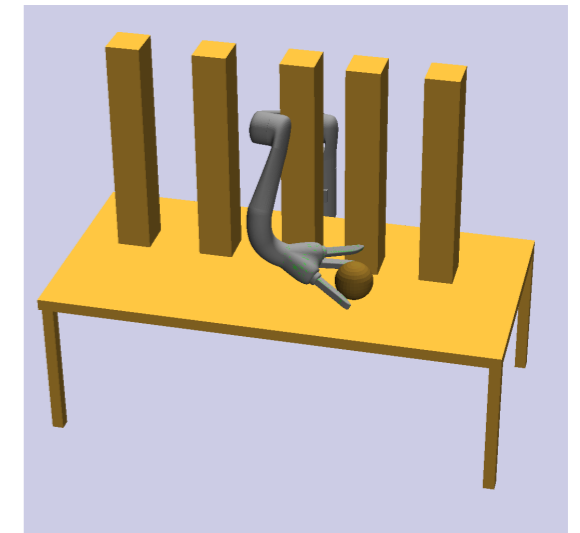
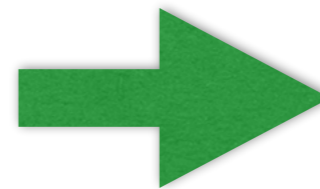
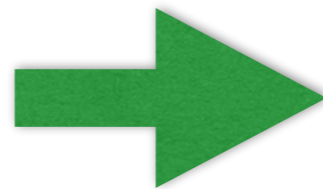


IK Solver

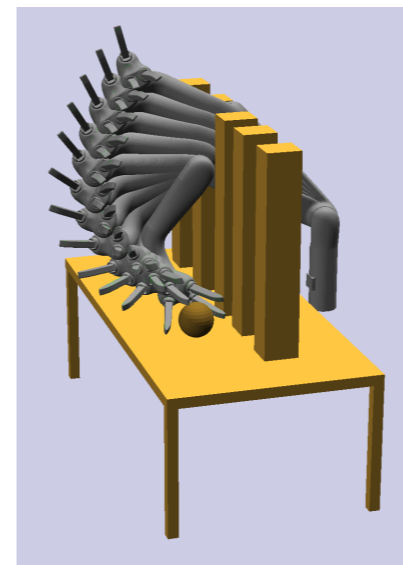
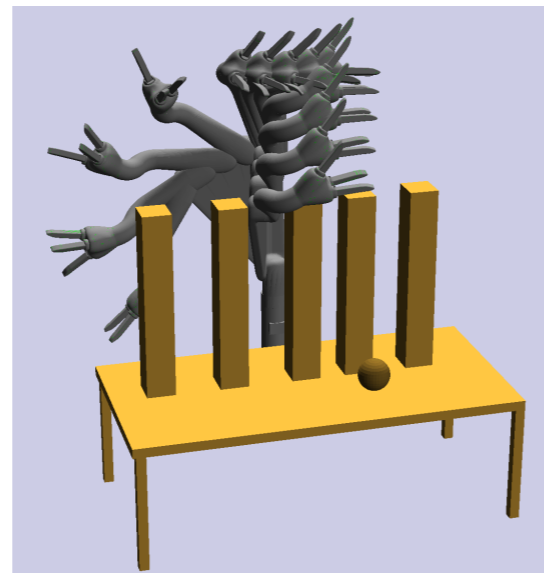
Motion Planning



start pose



goal



Control

Planning outputs a *sequence of robot poses*.

How to move directly to a pose from the current pose?

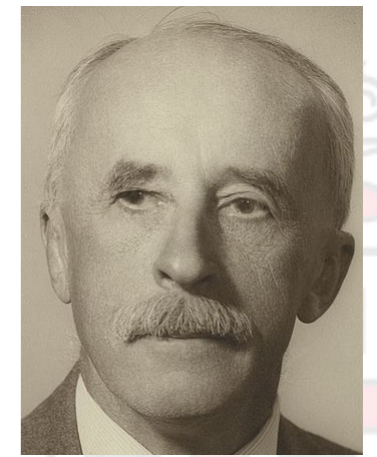
- Must send force to motors.
- How much?
- When?
- For how long?

Control theory:

- How to apply torque to motors
- Don't overshoot
- Don't undershoot
- Don't destabilize the robot.

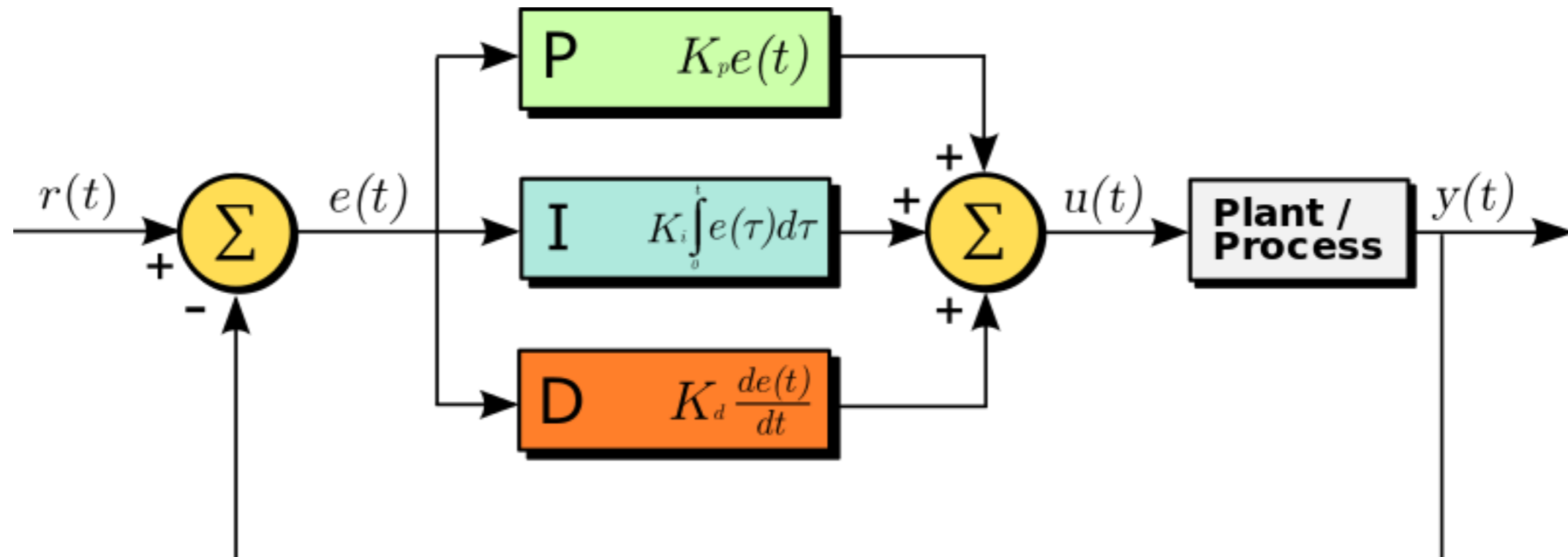


Control

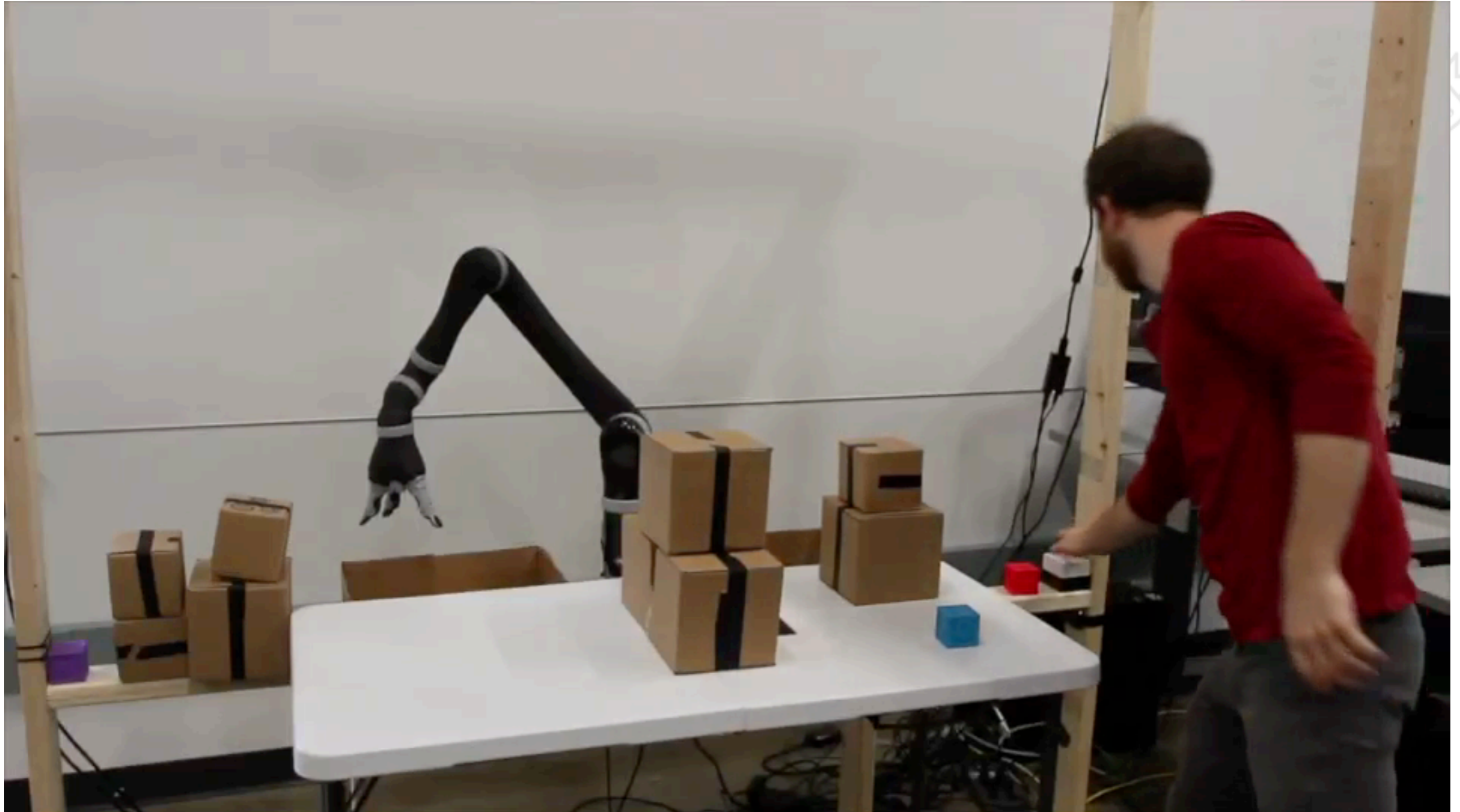


PID Control

- Move towards goal point with speed proportional to:
 - *Proportional* to distance (reduce error)
 - *Integral* term (defeat residual error)
 - *Differential* term (to dampen)



Robots in Motion

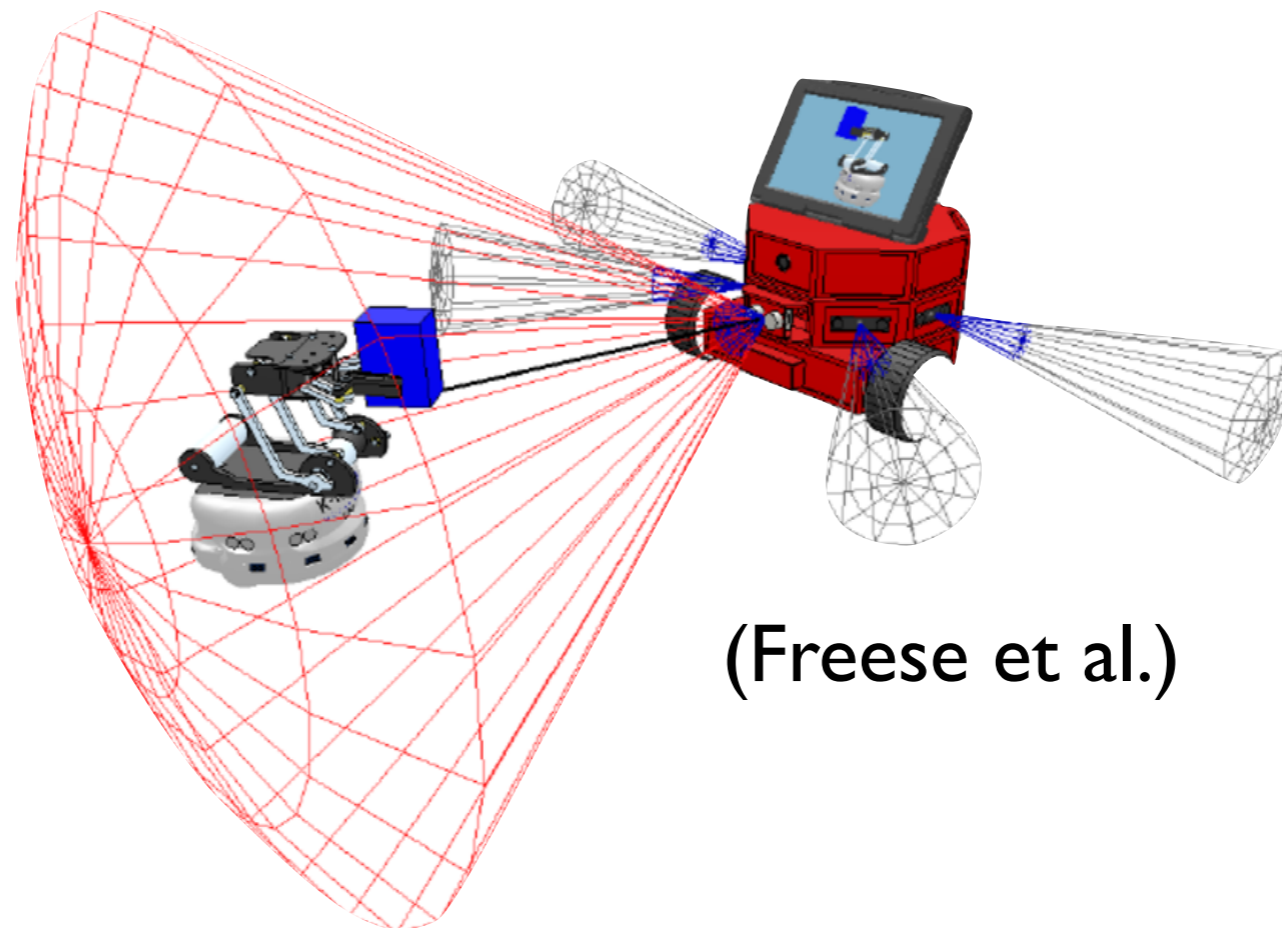


Low-Level Perception

Lots of questions here.

Simultaneous localization and mapping (SLAM)

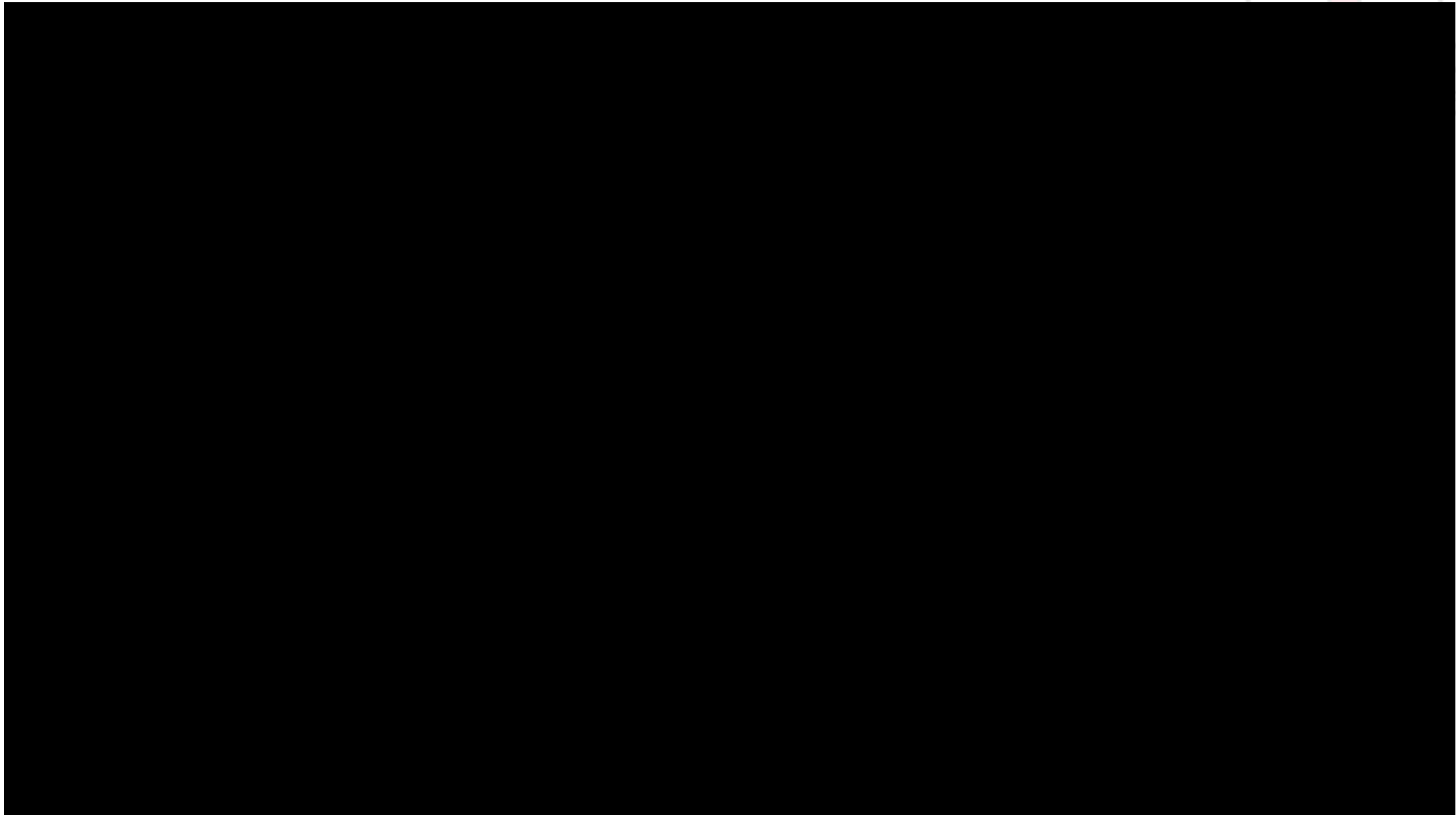
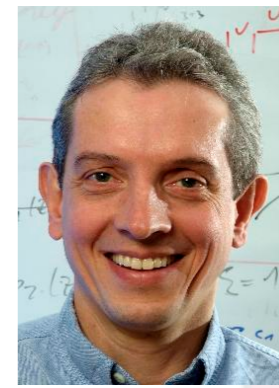
- Robots have limited perception.
- What does the building look like?
- Where is the robot in it?



(Freese et al.)



SLAM



SLAM

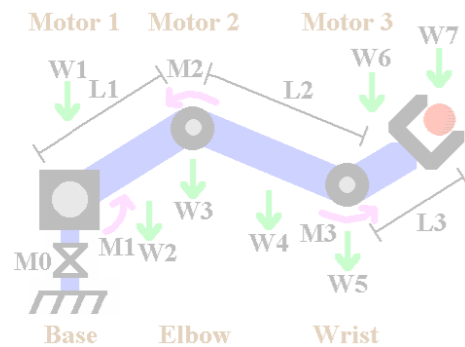


**1000 Kilometers Of
Appearance-Only SLAM**

FabMap 2.0

Robotics

Low-Level



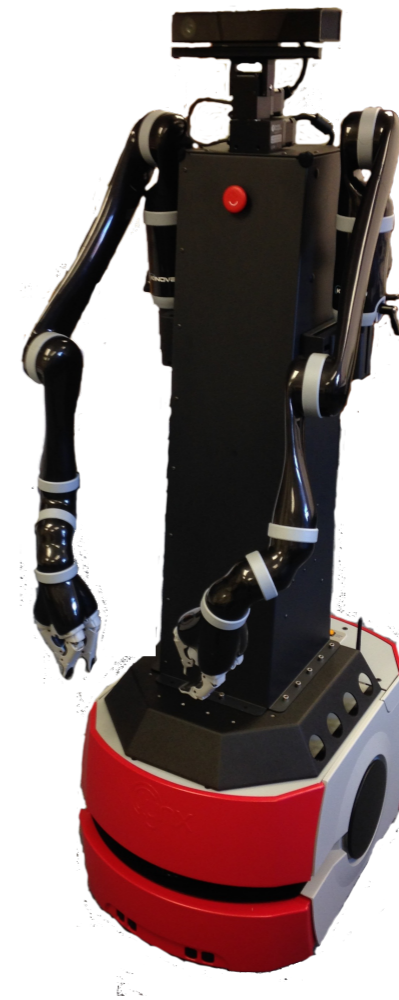
Mid-Level



High-Level

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)
```

High-level Reasoning



Low-level Control



Mid-Level Goals

Given the ability to:

- Localize
- Navigate
- Motion plan
- Move to a given pose

... what next?

Object manipulation



Grasping

Where to grasp?

One approach:

- Generate large numbers of grasps (e.g., geometric)
- Train a grasp classifier to recognize good grasps



Grasping in Dense Clutter

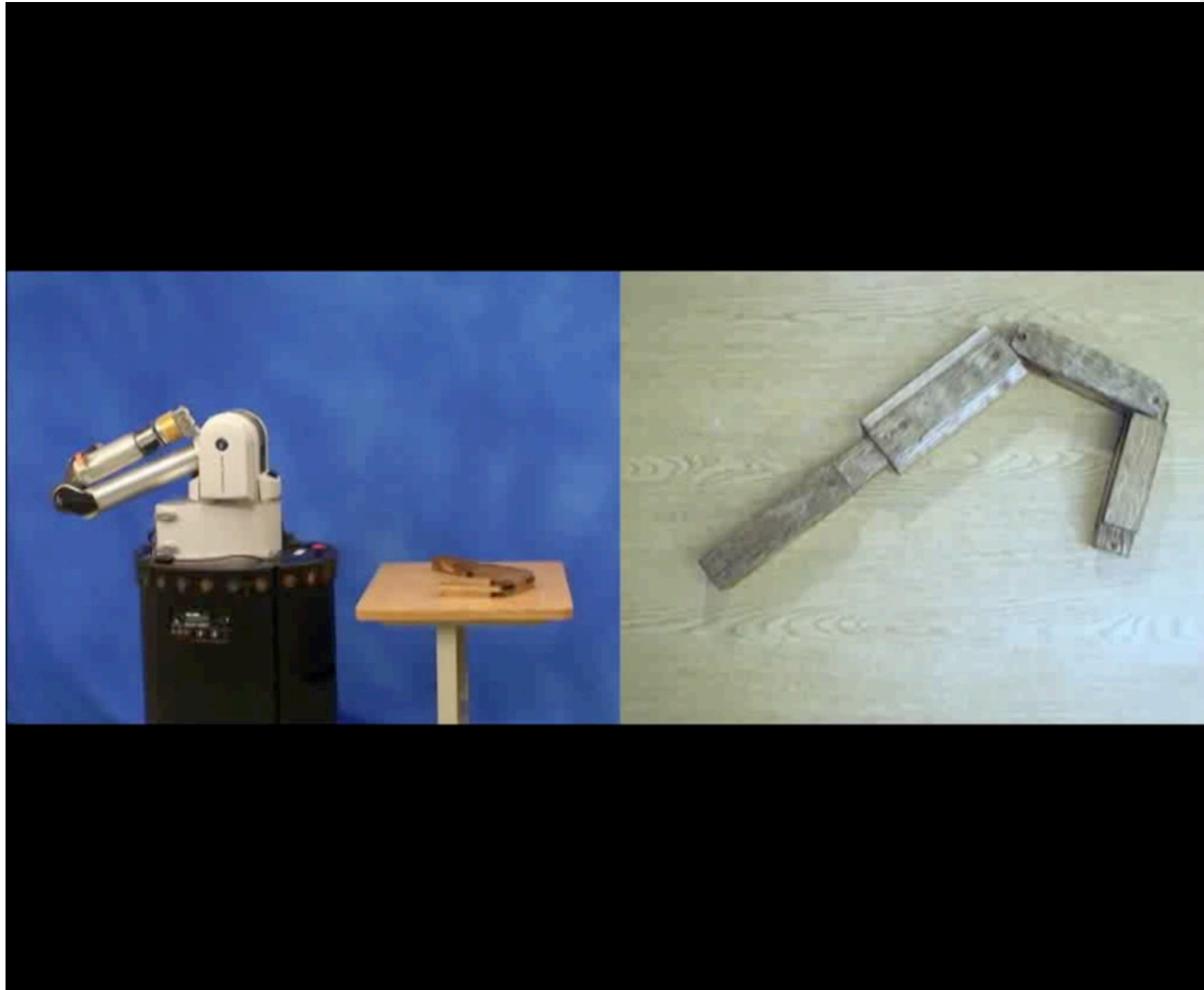


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College of Computer and Information Science

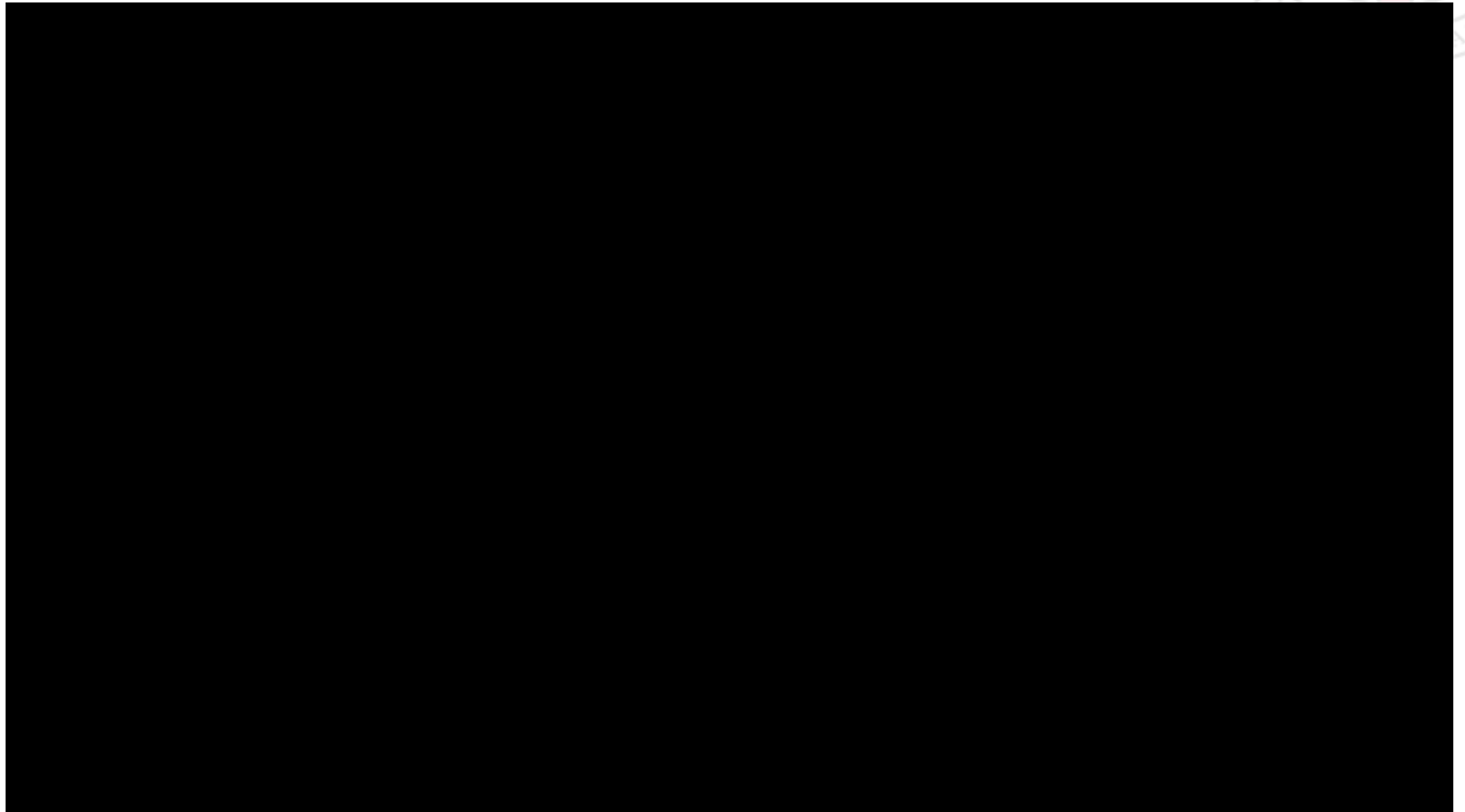
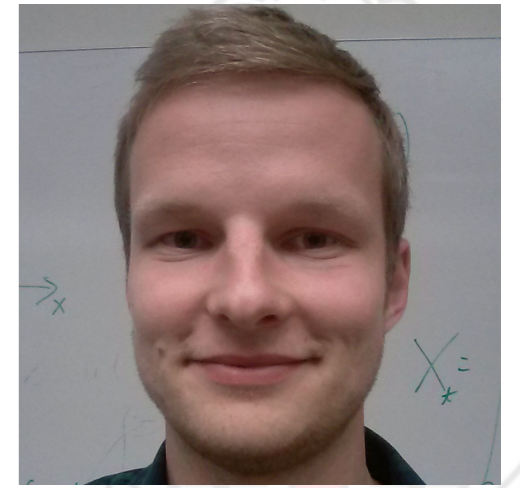
Exploring Objects



How many degrees of freedom does an object have?

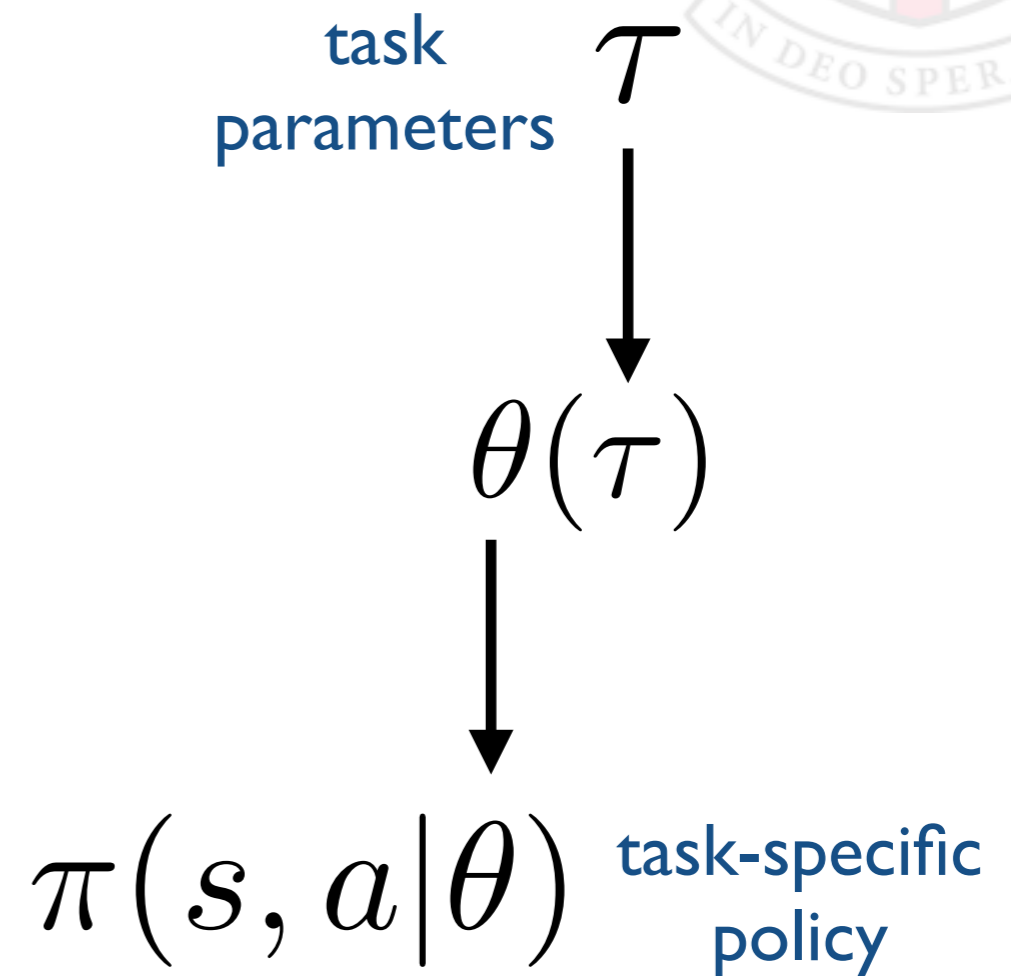
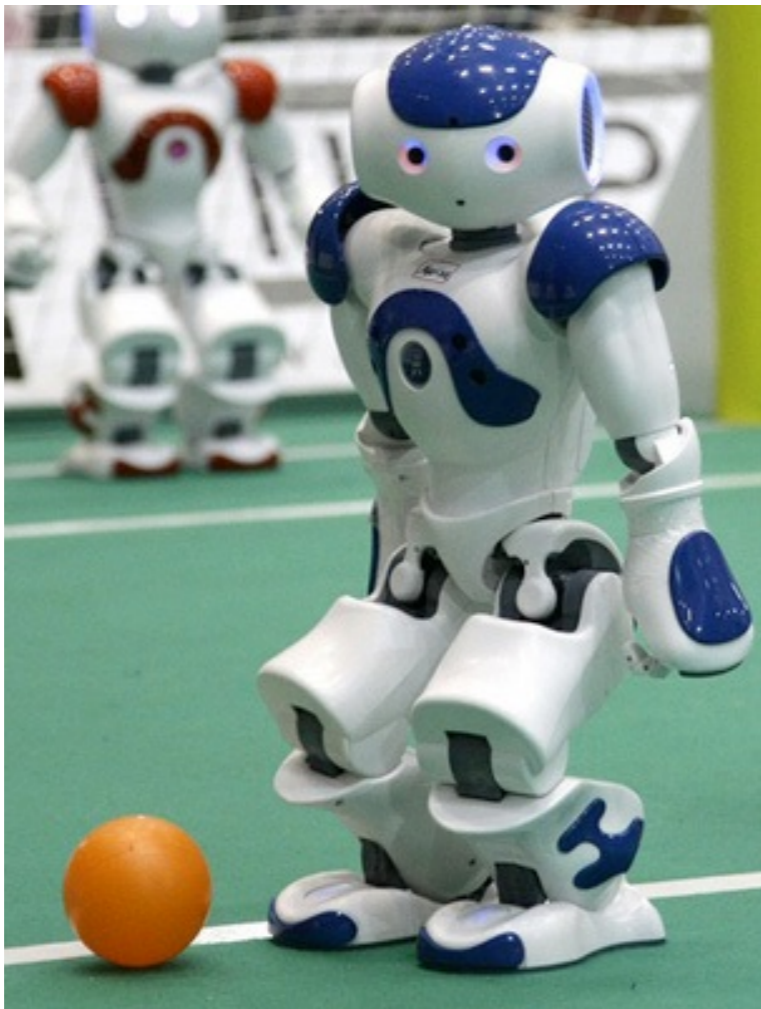


Exploring Objects



Learning Motor Skills

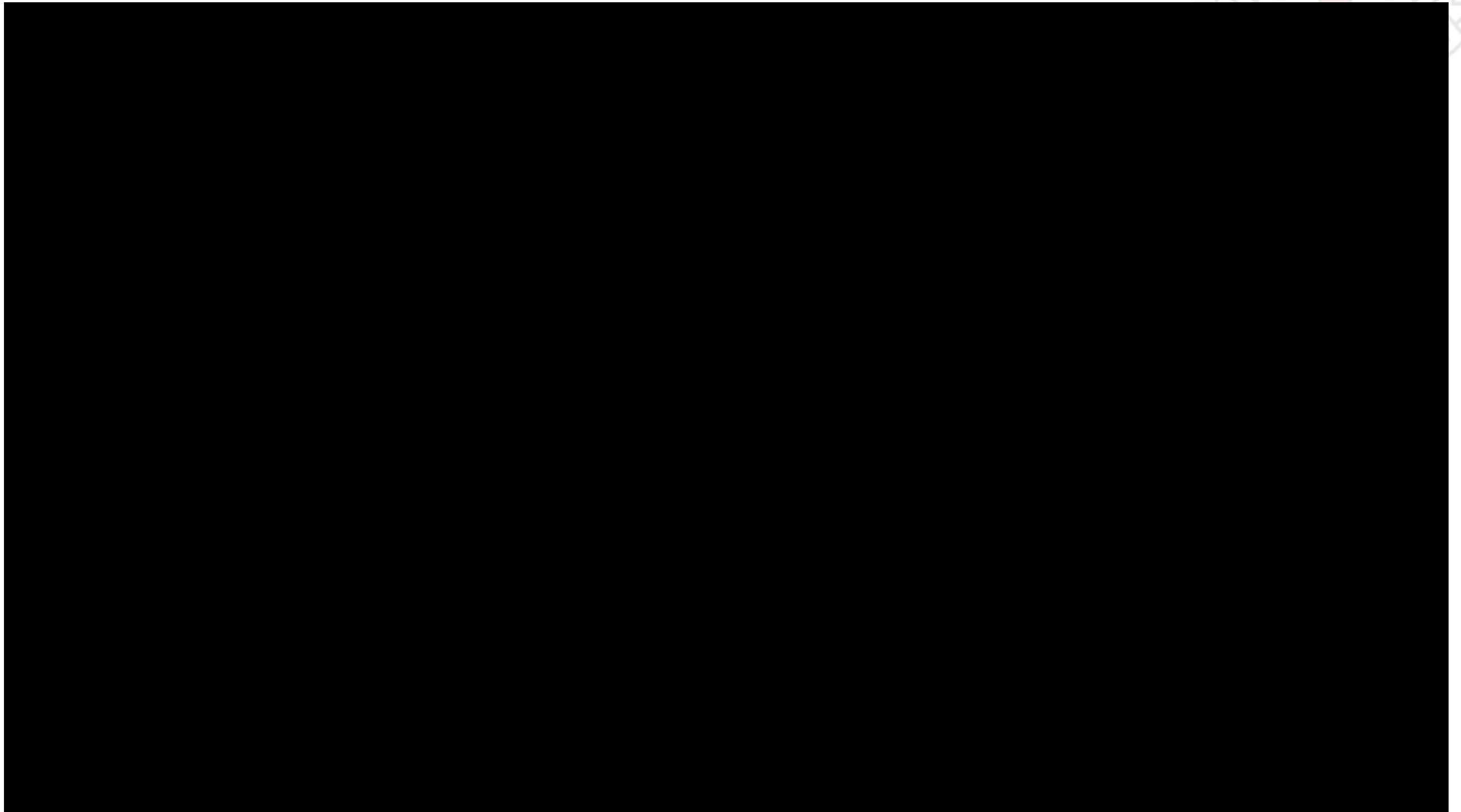
We've seen this in RL, but one more: **parameterized skills**.



General skills:

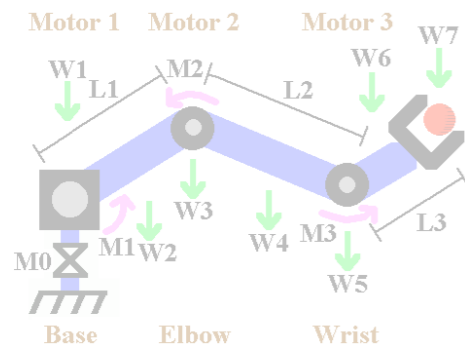
- Single skill to solve a *parametrized family* of problems.
- More flexible skills, avoids re-learning

Learning Motor Skills



Robotics

Low-Level



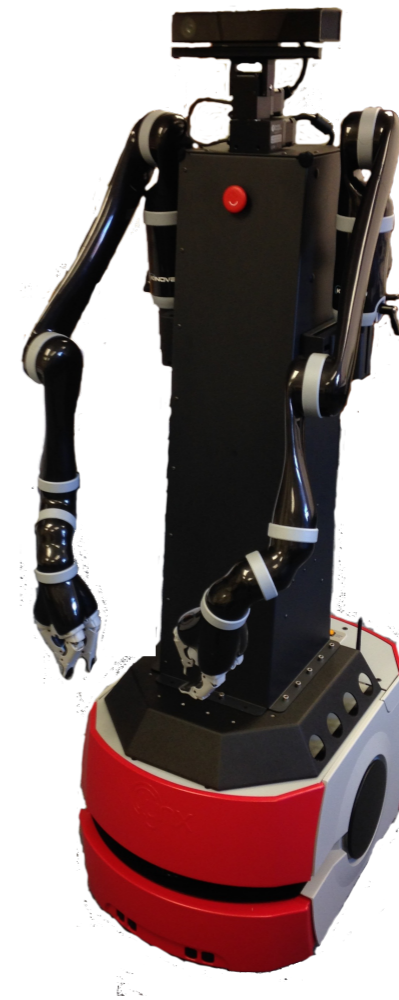
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High-level Reasoning



Low-level Control



Planning and Reasoning

Given:

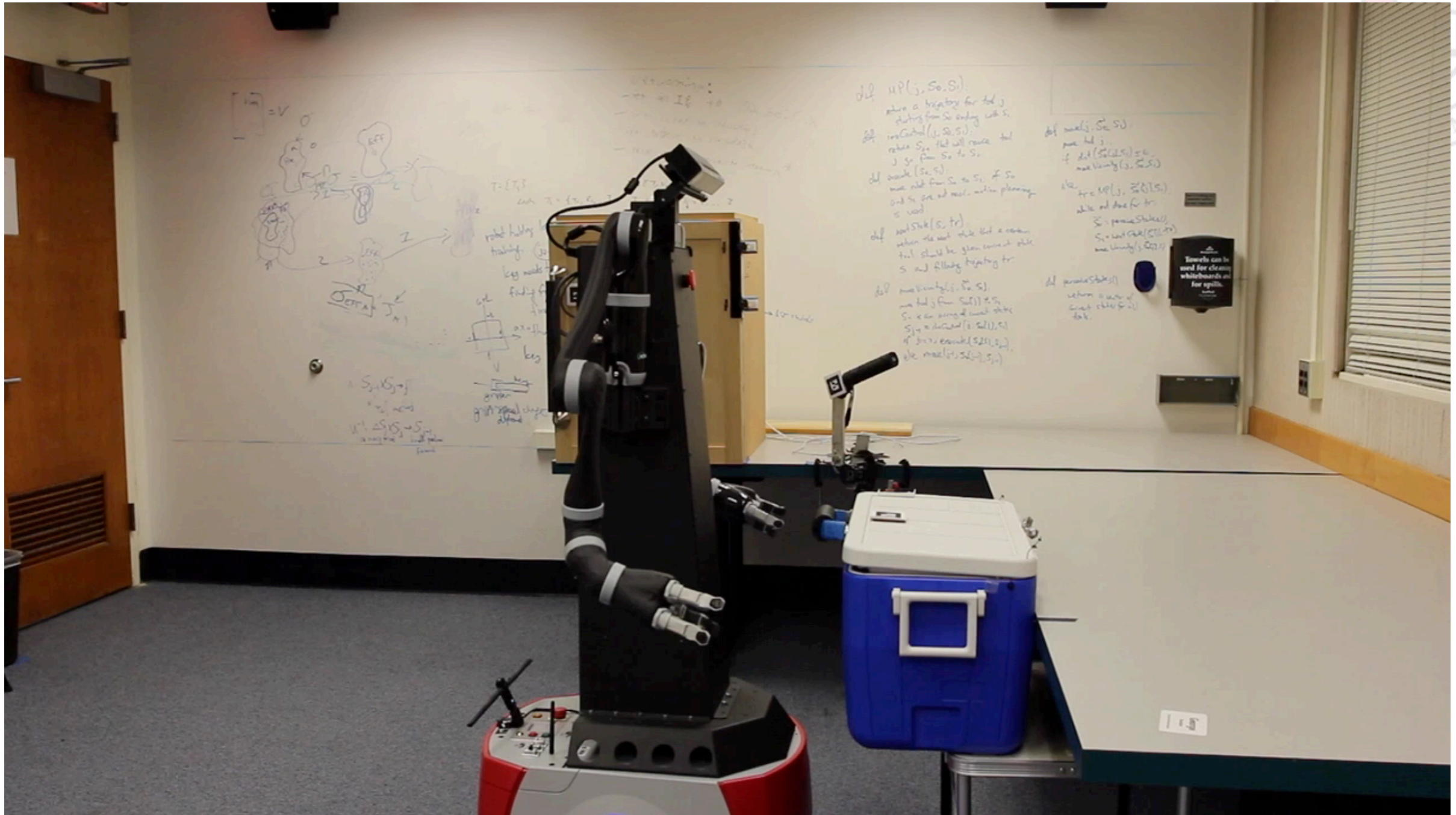
- Localize
- Navigate
- Motion plan
- Move to a given pose
- Recognize objects
- Manipulate objects
- Learning skills

... what next?

Planning using these as a foundation.

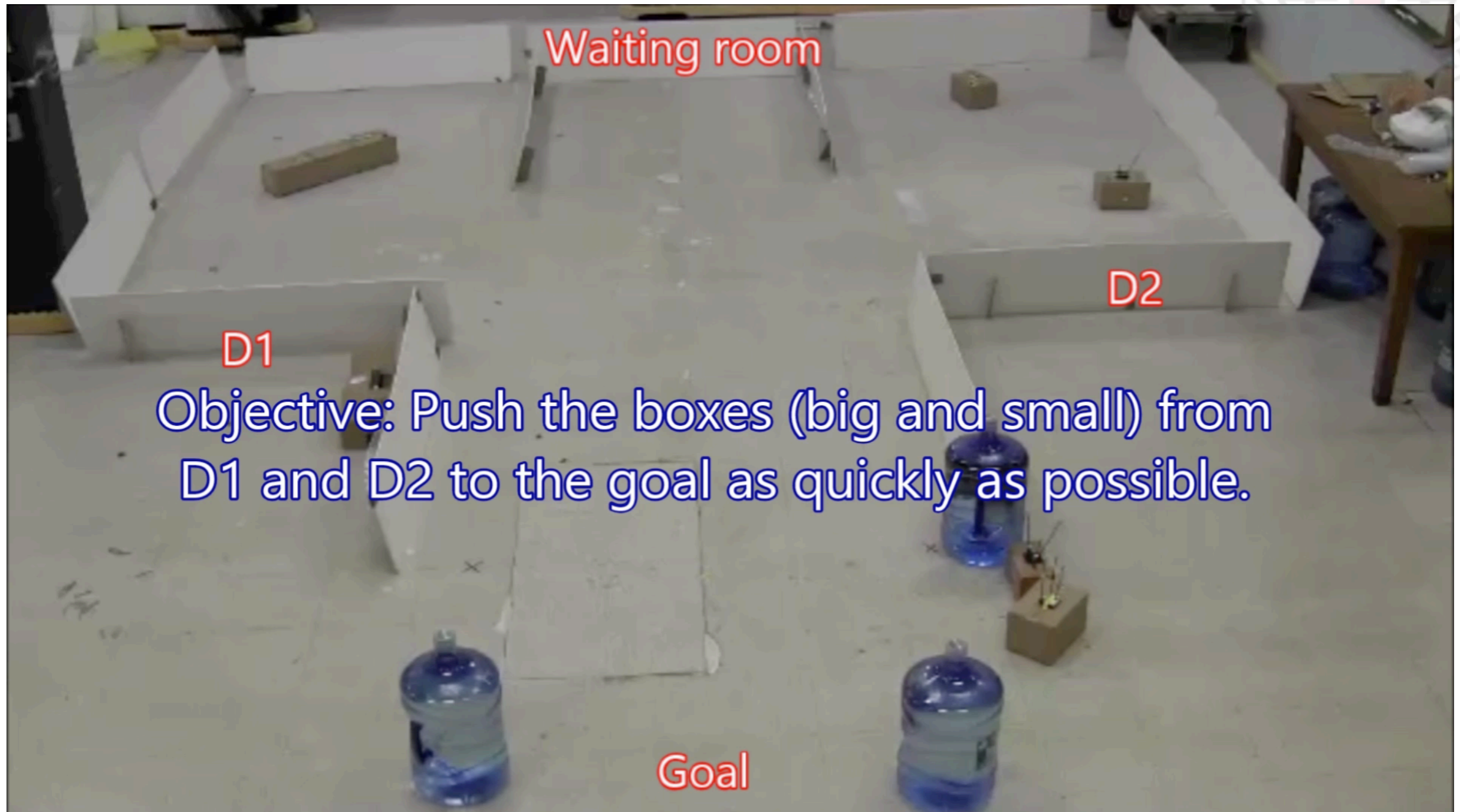
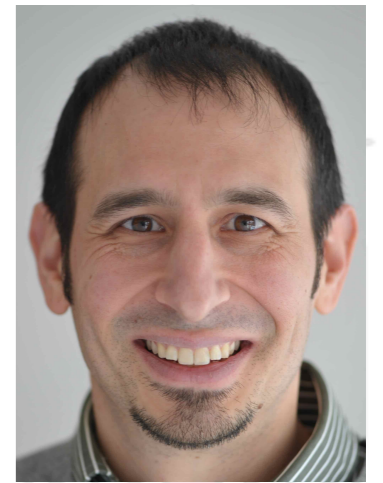


Planning



Multi-Robot Planning

Decentralized, partially-observable MDPs

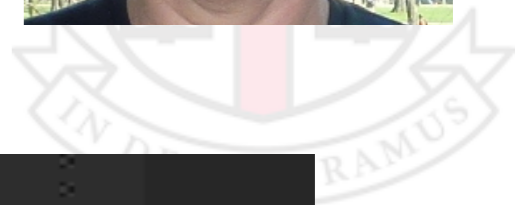


Robocup



Cobots

1,000 km of autonomous operation



Robotics

