

Robotics

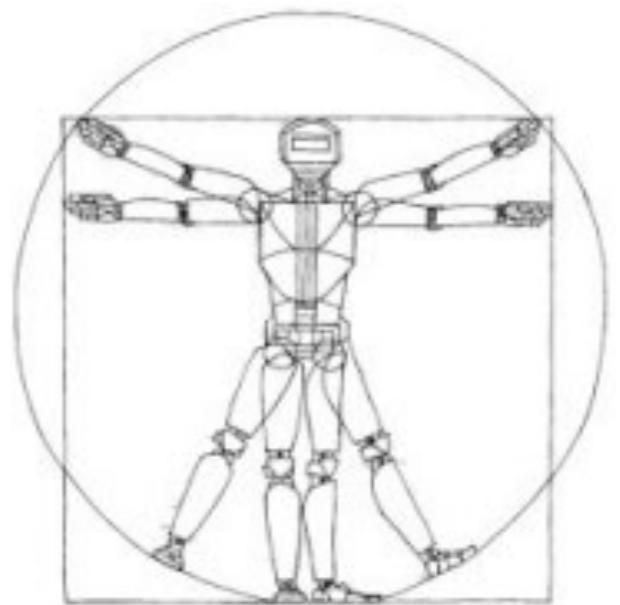
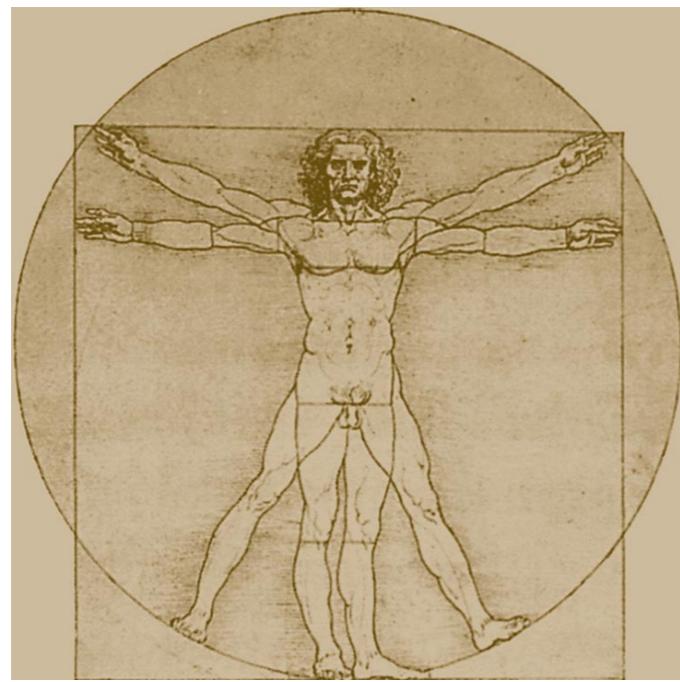
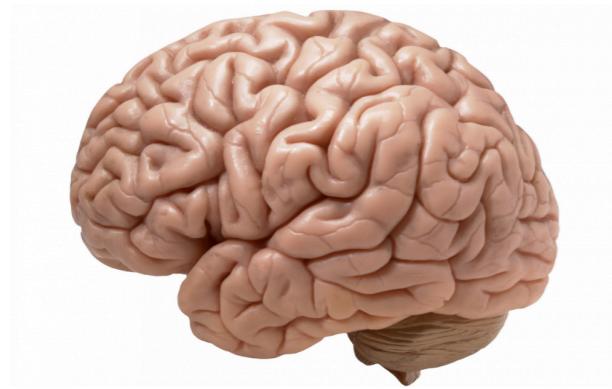
George Konidaris
gdk@cs.brown.edu

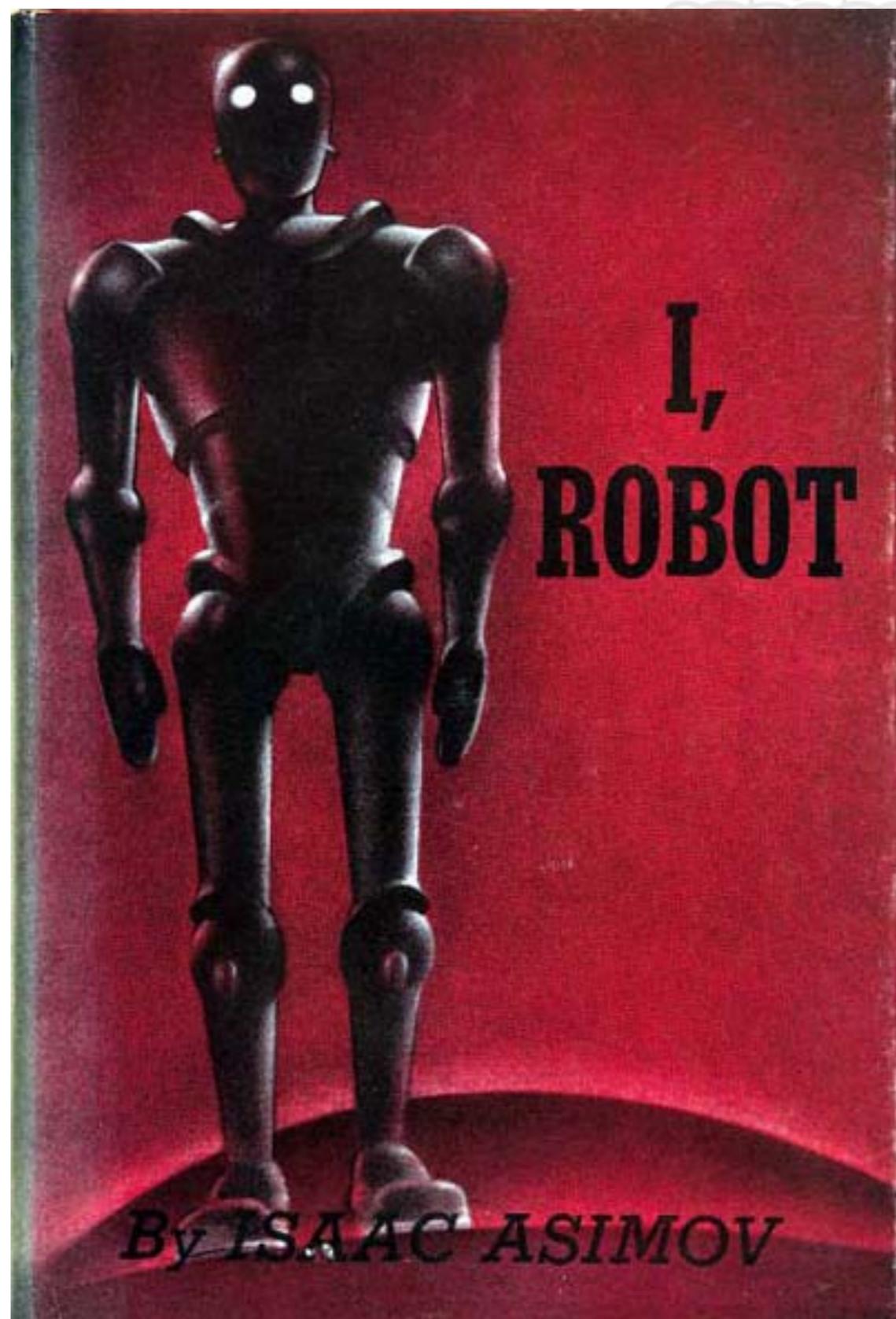
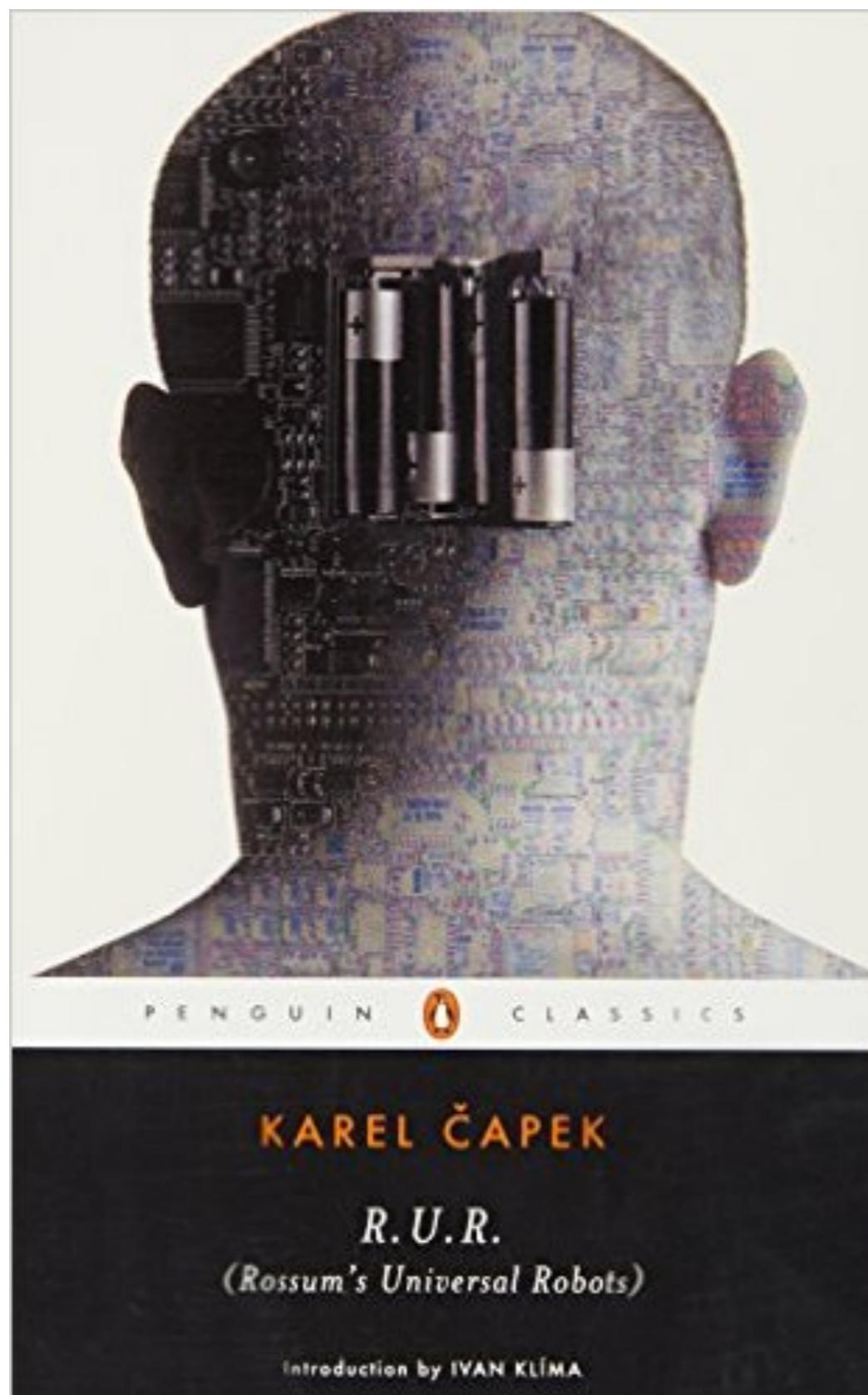
Fall 2021

Robots



Robotics as AI

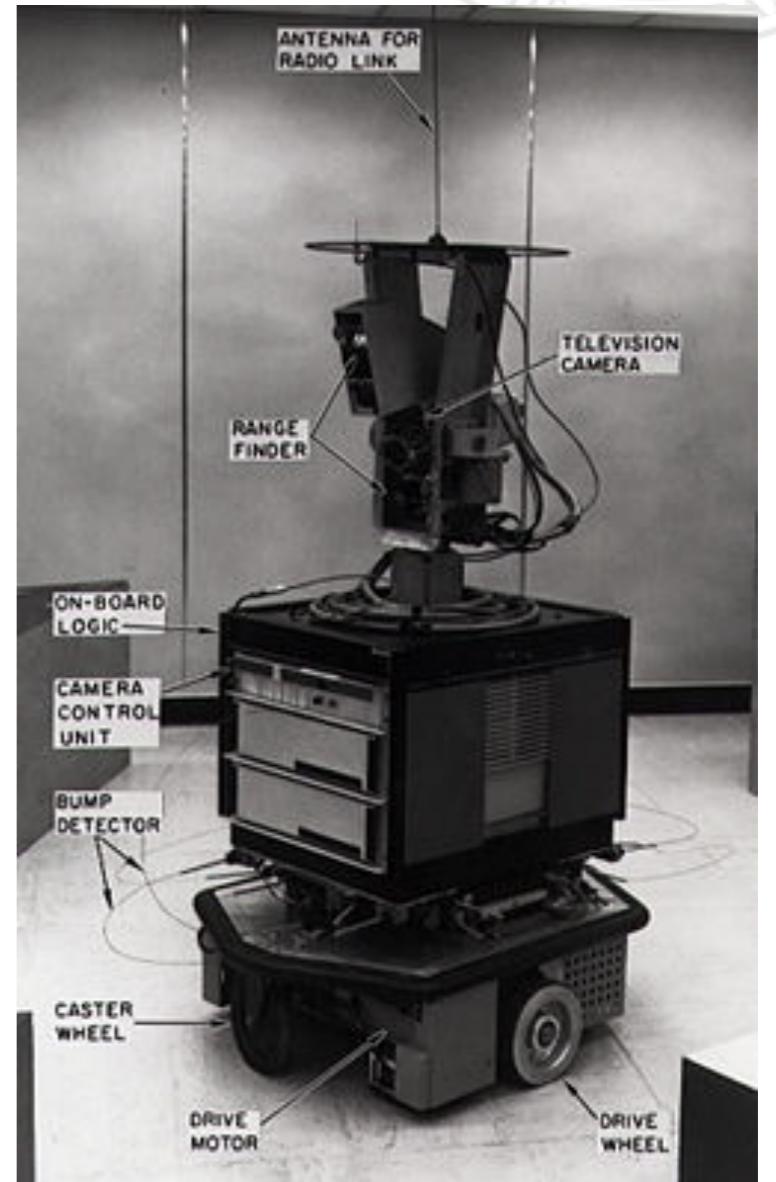




Robotics

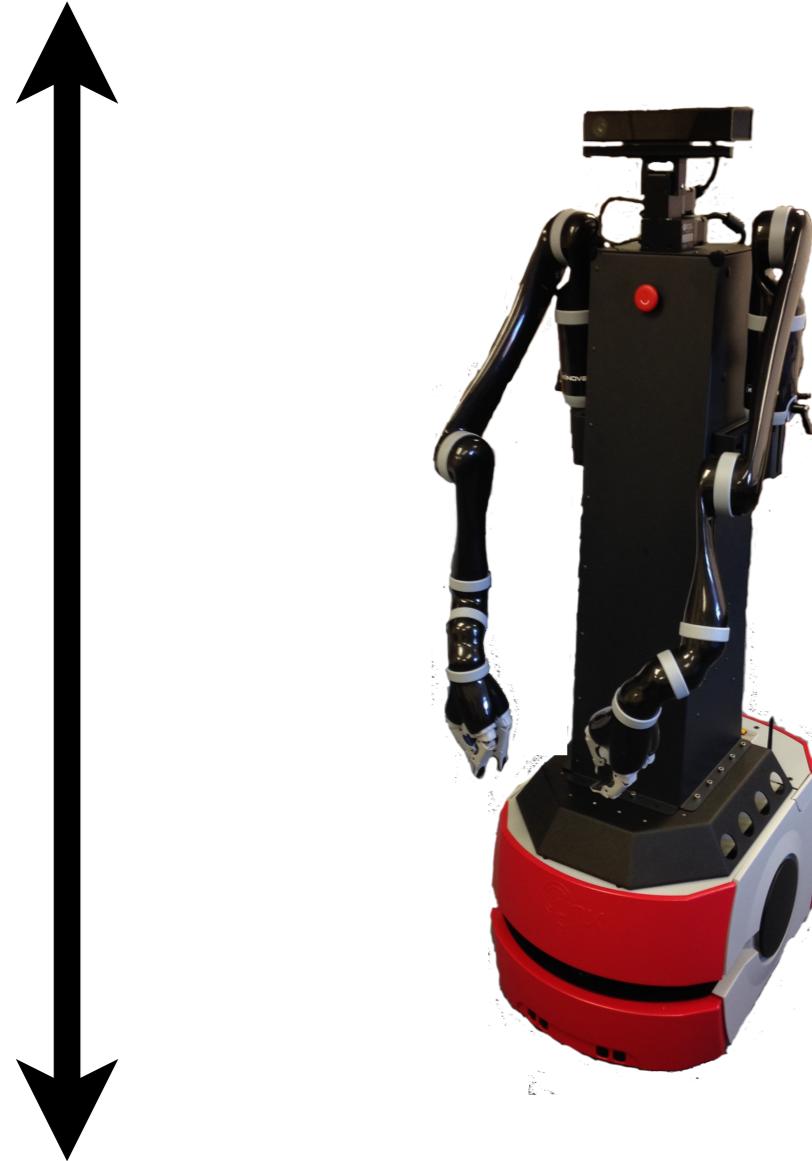
Shakey the Robot 1966 - 1972

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



Robotics

High-level Reasoning



Low-level Control

Discrete, abstract, symbolic.

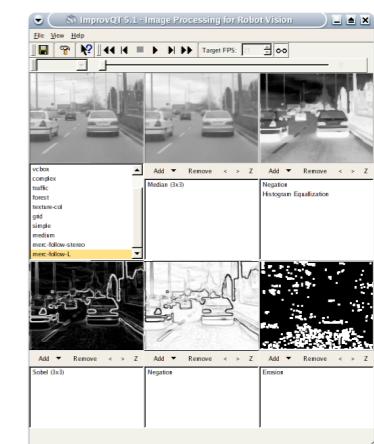
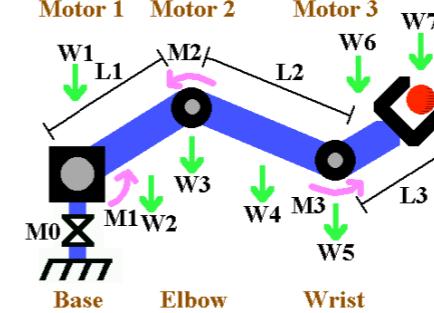
PourTea :

Pre : HoldingKettle \wedge KettleFull

Effect : \neg KettleFull \wedge TeaPoured



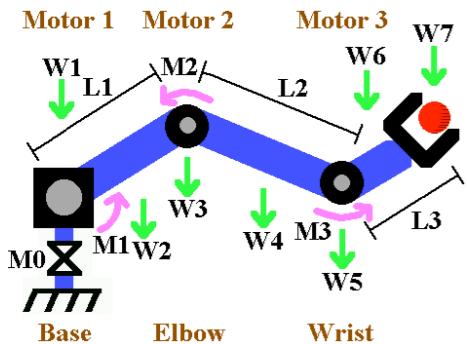
Continuous, noisy, locally and partially observable, sensorimotor space.





Robotics

Low-Level



High-level Reasoning

Mid-Level



High-Level

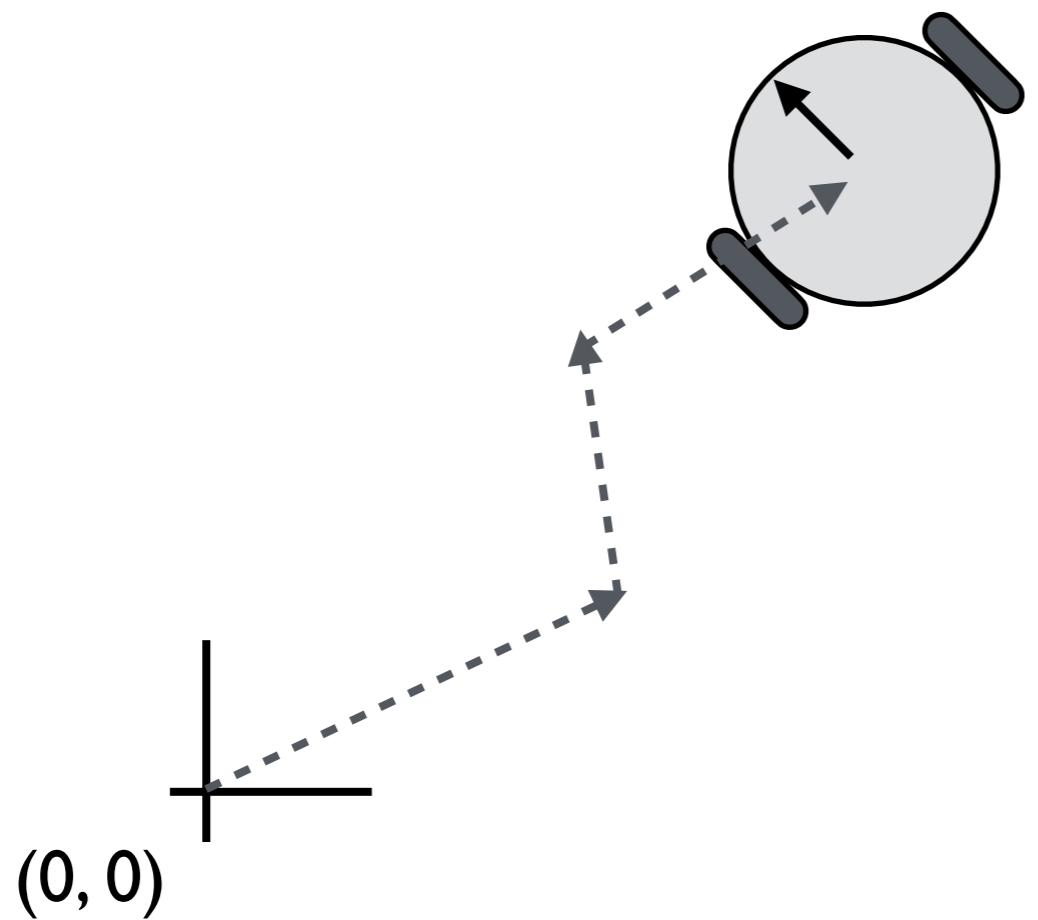
```
(:action pick_up2
:parameters ()
:precondition (and (symbol1) (symbol3)
                     (symbol5) (symbol6) (symbol11))
:effect (probabilistic
 0.0559 (and)
 0.9441 (and (symbol12) (not (symbol13))
            (decrease (reward) 53.42))
      )
)
```



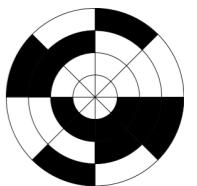
Low-level Control

Kinematics

The first key question: where am I?

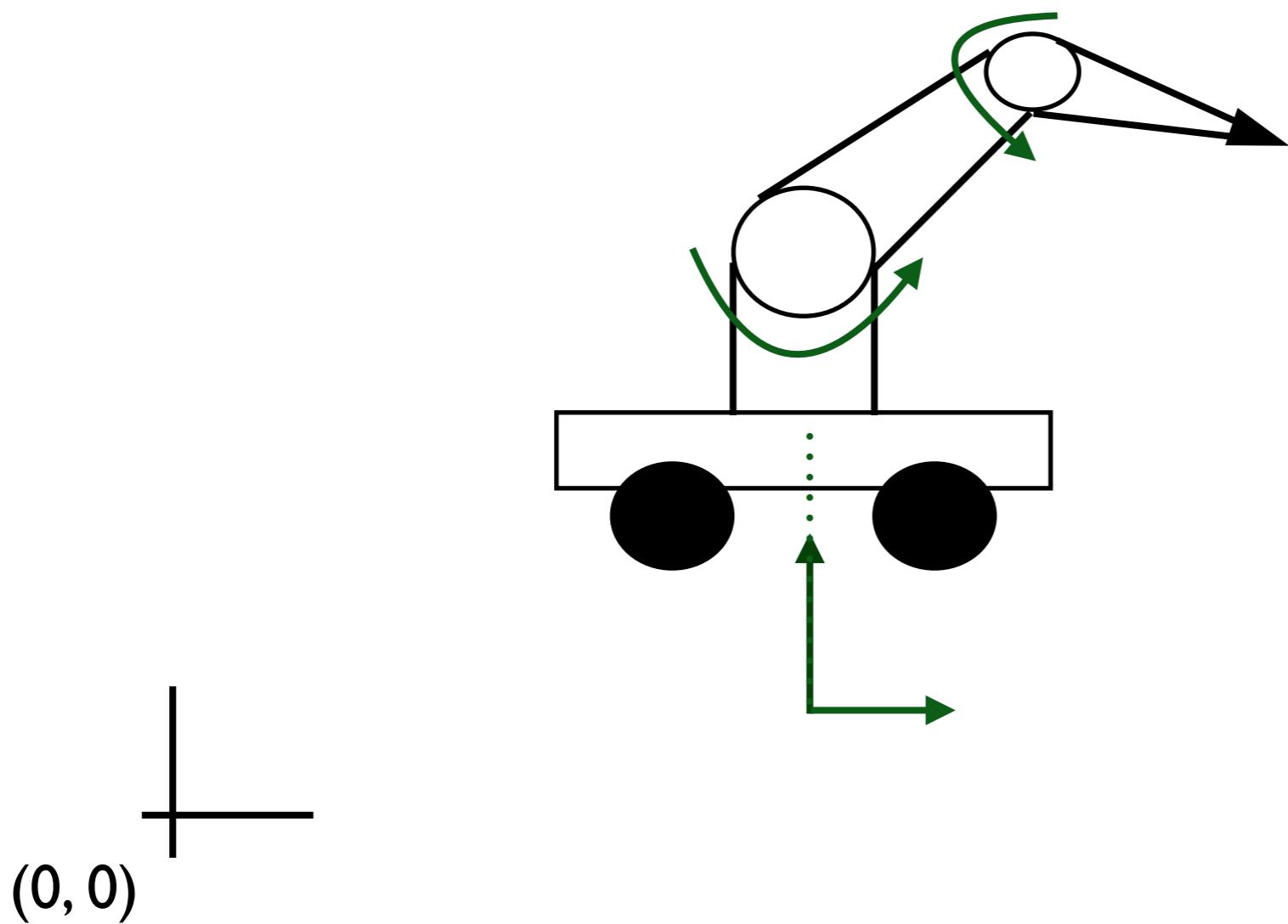


Relevant sensor:
Encoders



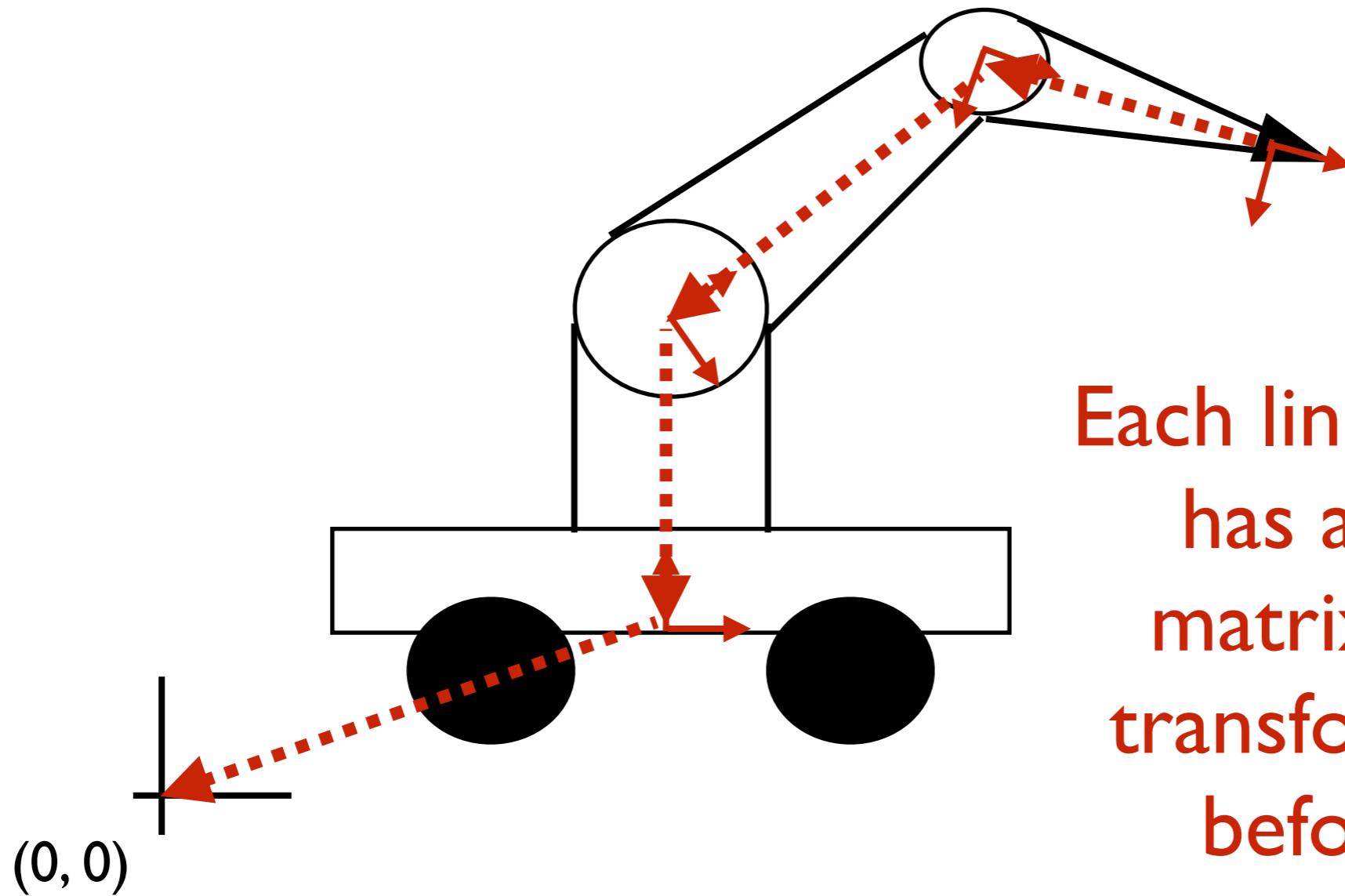
Kinematics

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

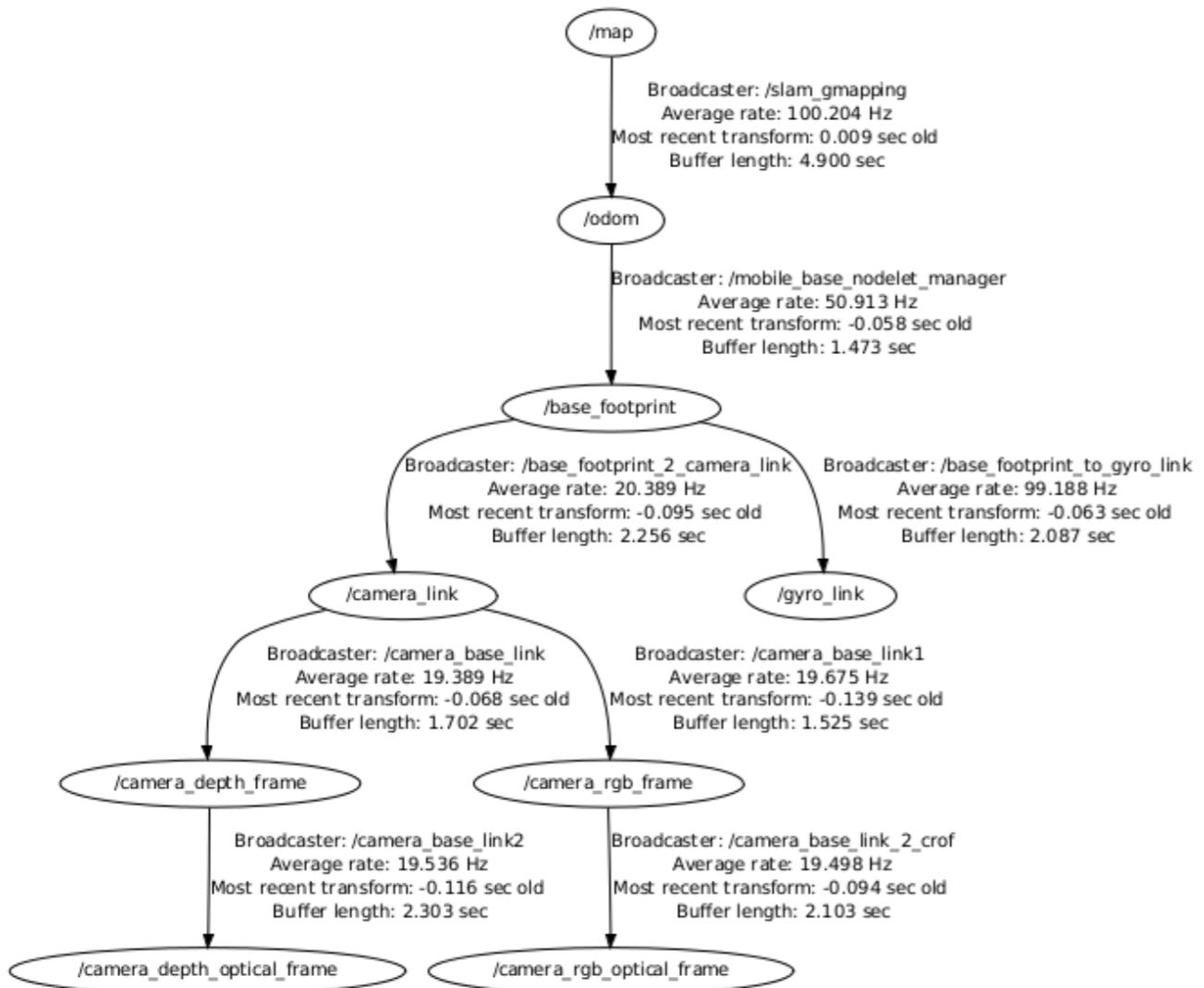
Data given in the coordinate frame of the sensor.





Kinematics

Matrices linked together in a tree

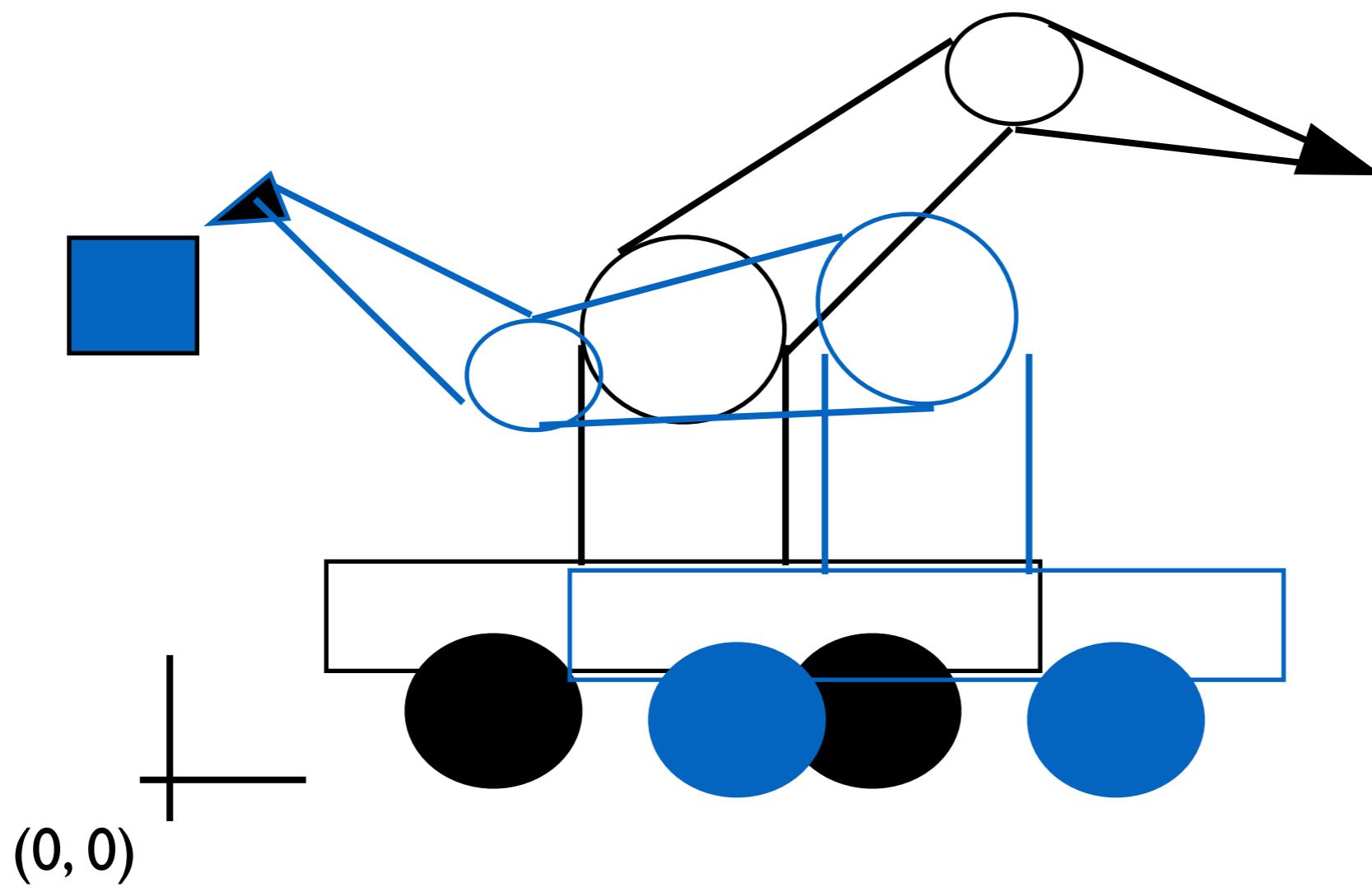




Inverse Kinematics

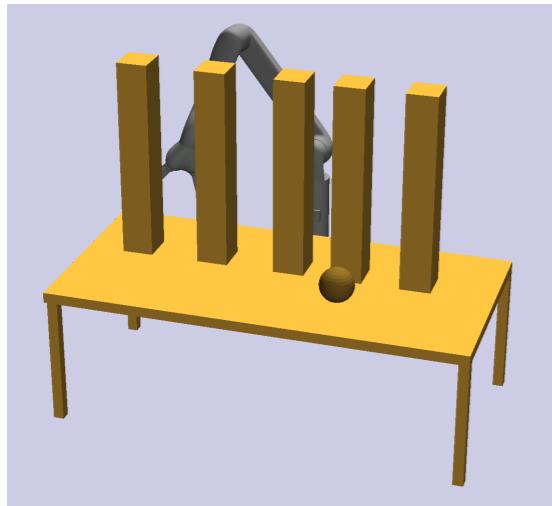
The reverse question.

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

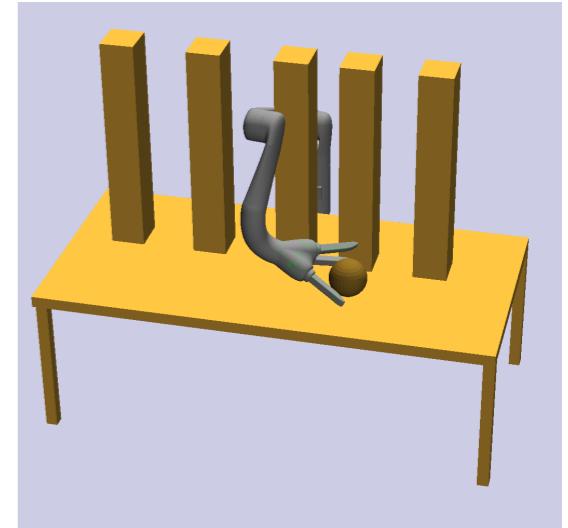
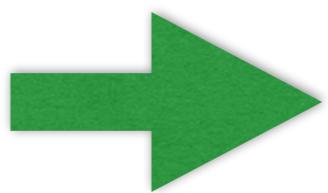
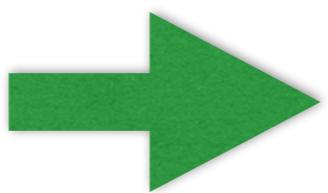


IK Solver

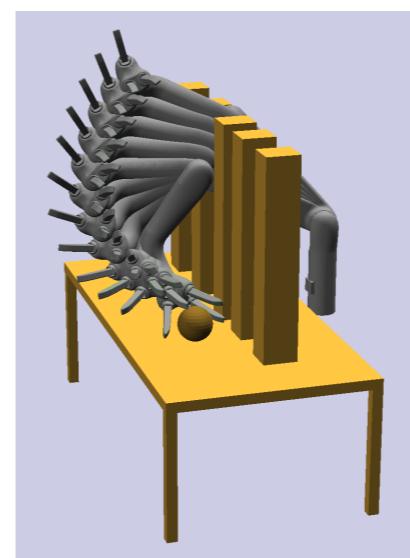
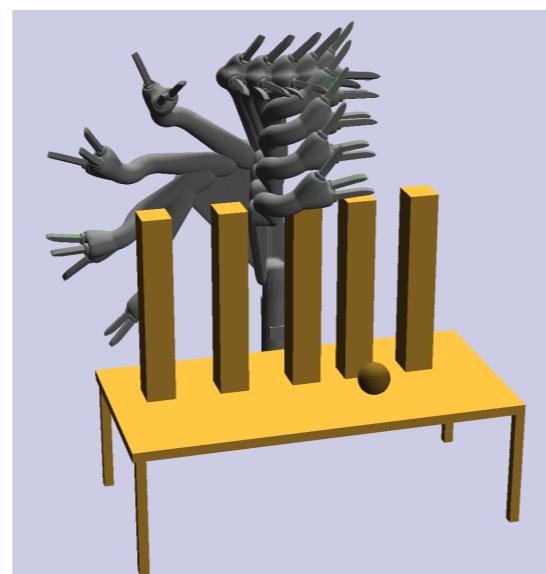
Motion Planning



start pose



goal



Control

Planning outputs a sequence of *robot poses*.

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

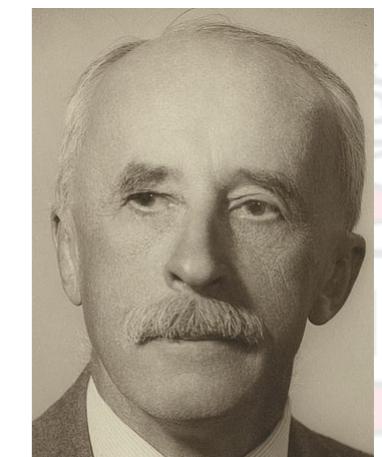
- Must send force to motors.
- How much?
- When?
- For how long?

Control theory:

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

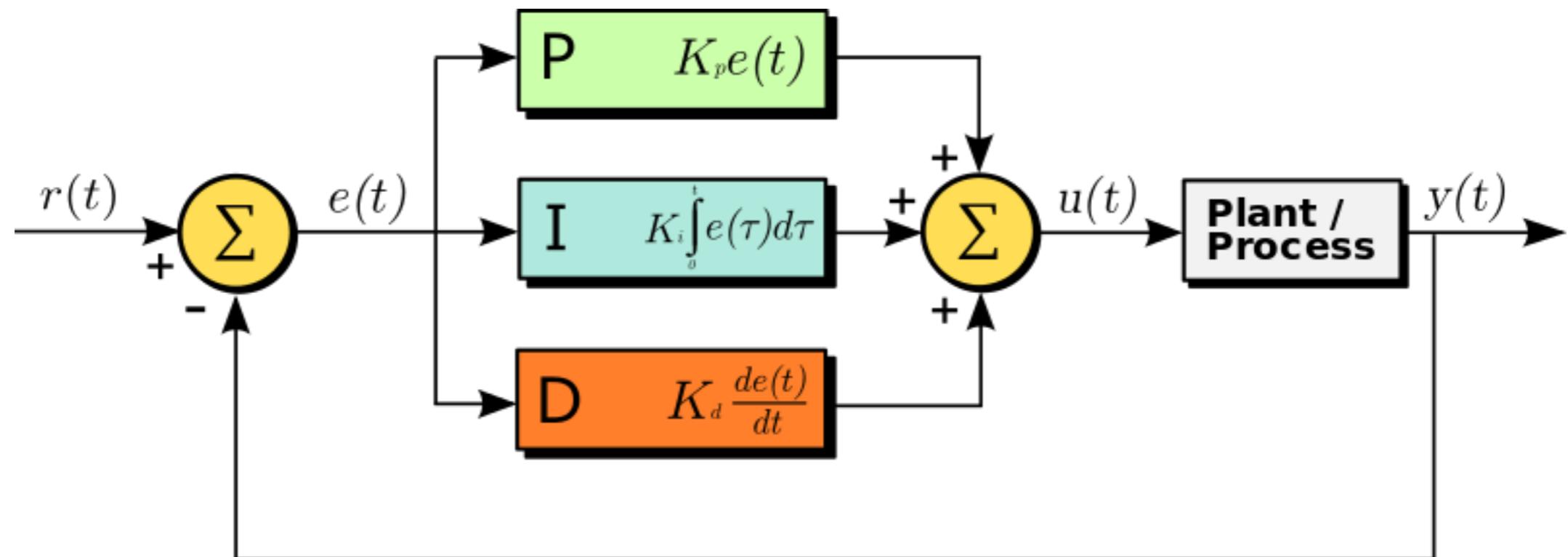


Control



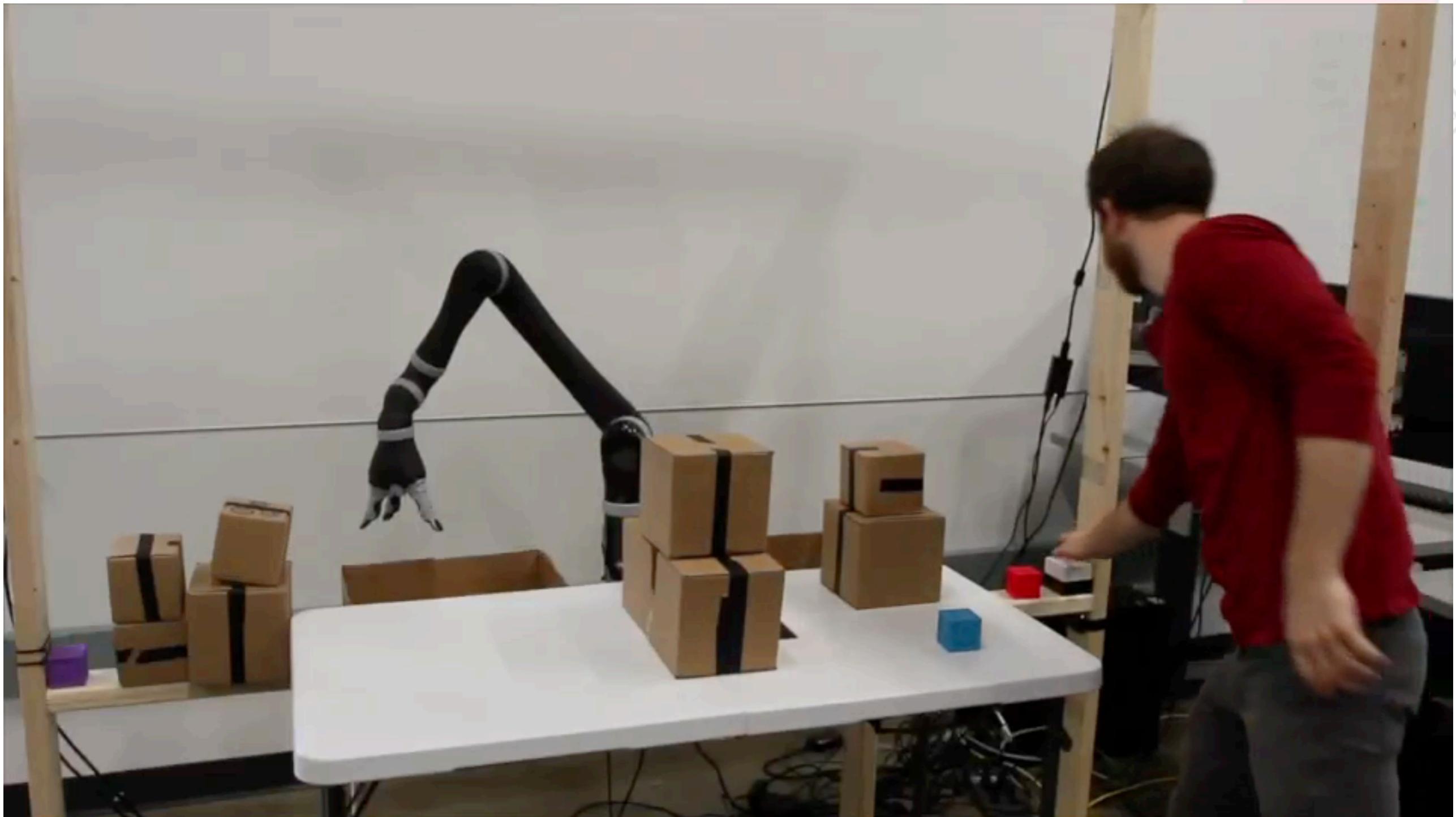
PID Control

- 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



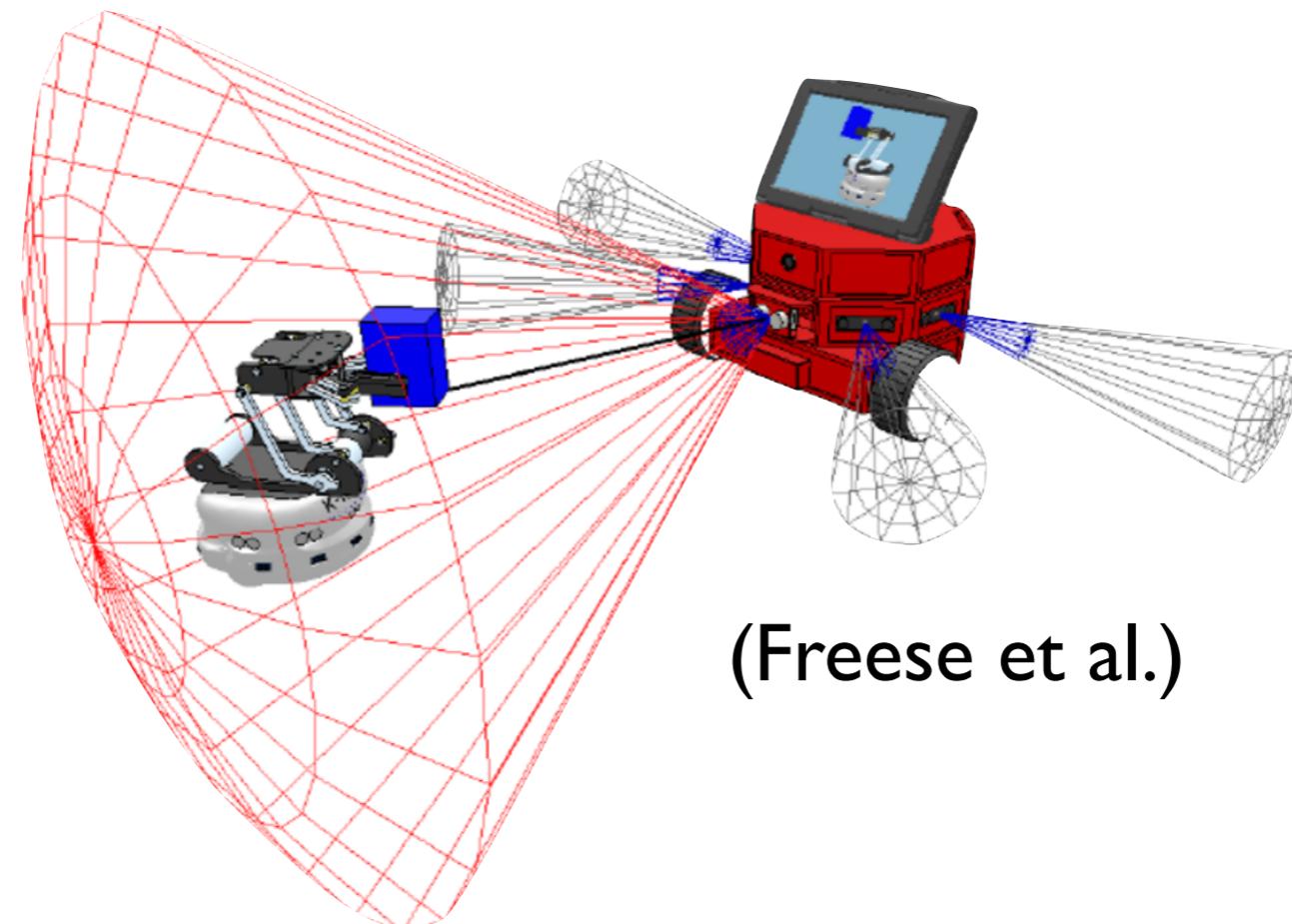
Low-Level Perception



Lots of questions here.

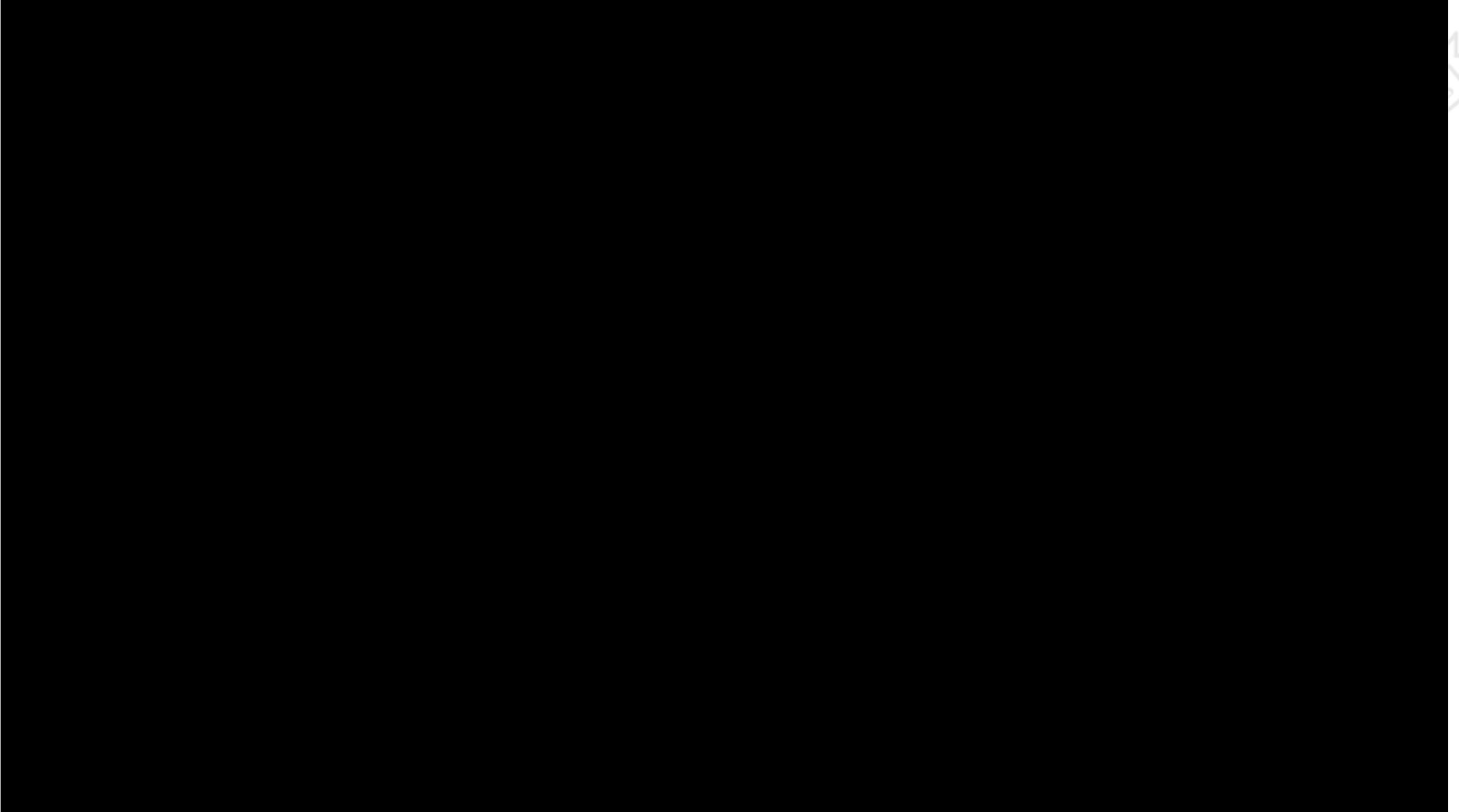
Simultaneous localization and mapping (SLAM)

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



(Freese et al.)

SLAM



SLAM



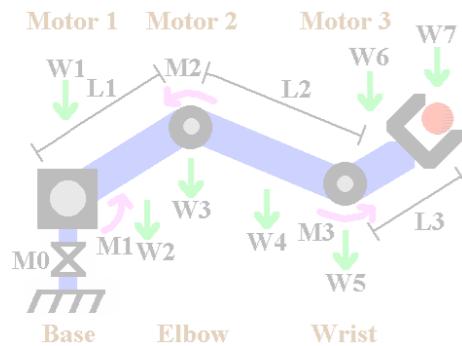
1000 Kilometers Of
Appearance-Only SLAM

FabMap 2.0



Robotics

Low-Level



High-level Reasoning



Mid-Level



High-Level

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            (decrease (reward) 53.42))
      )
)
```



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

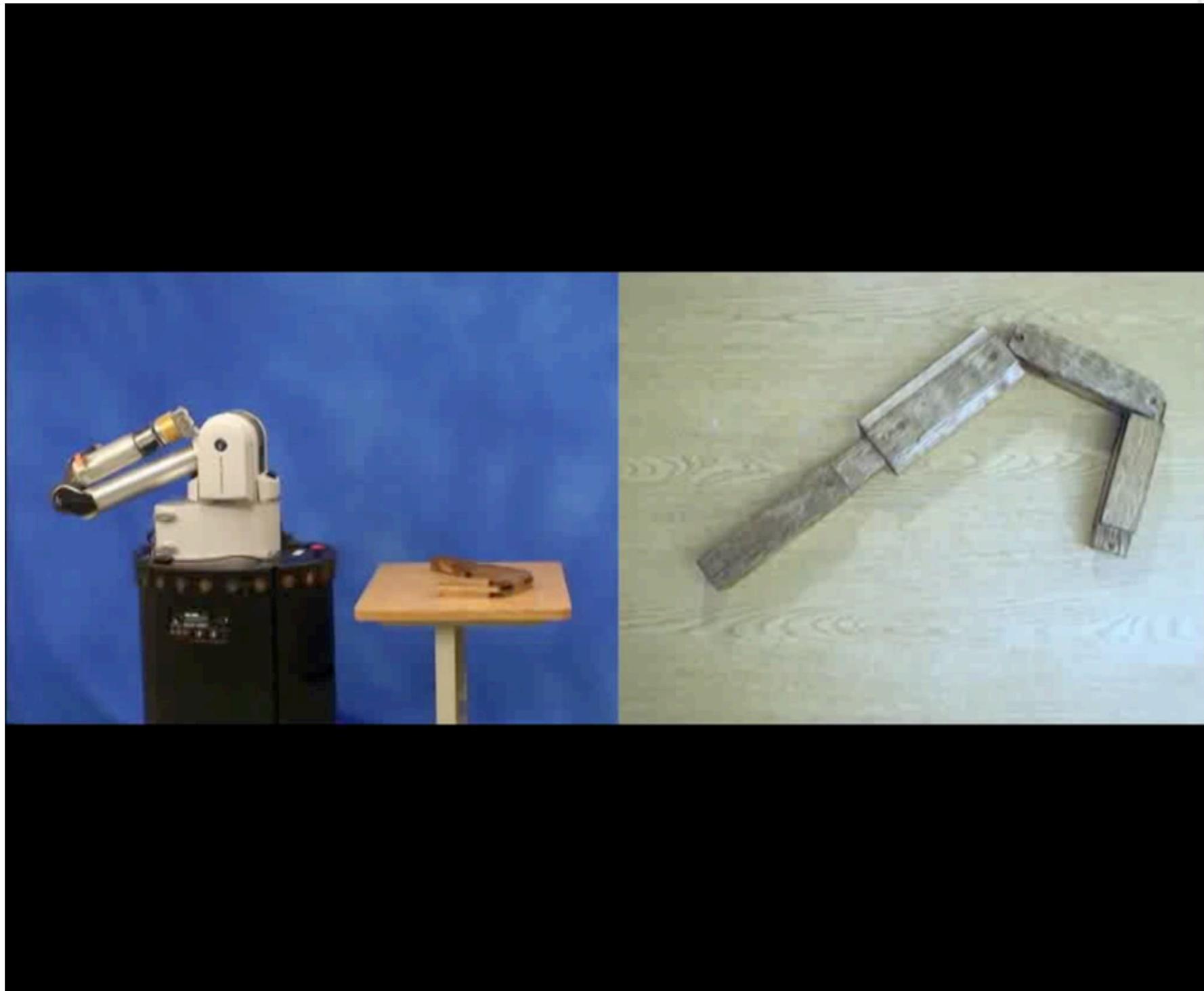


Northeastern University
College of Computer and Information Science

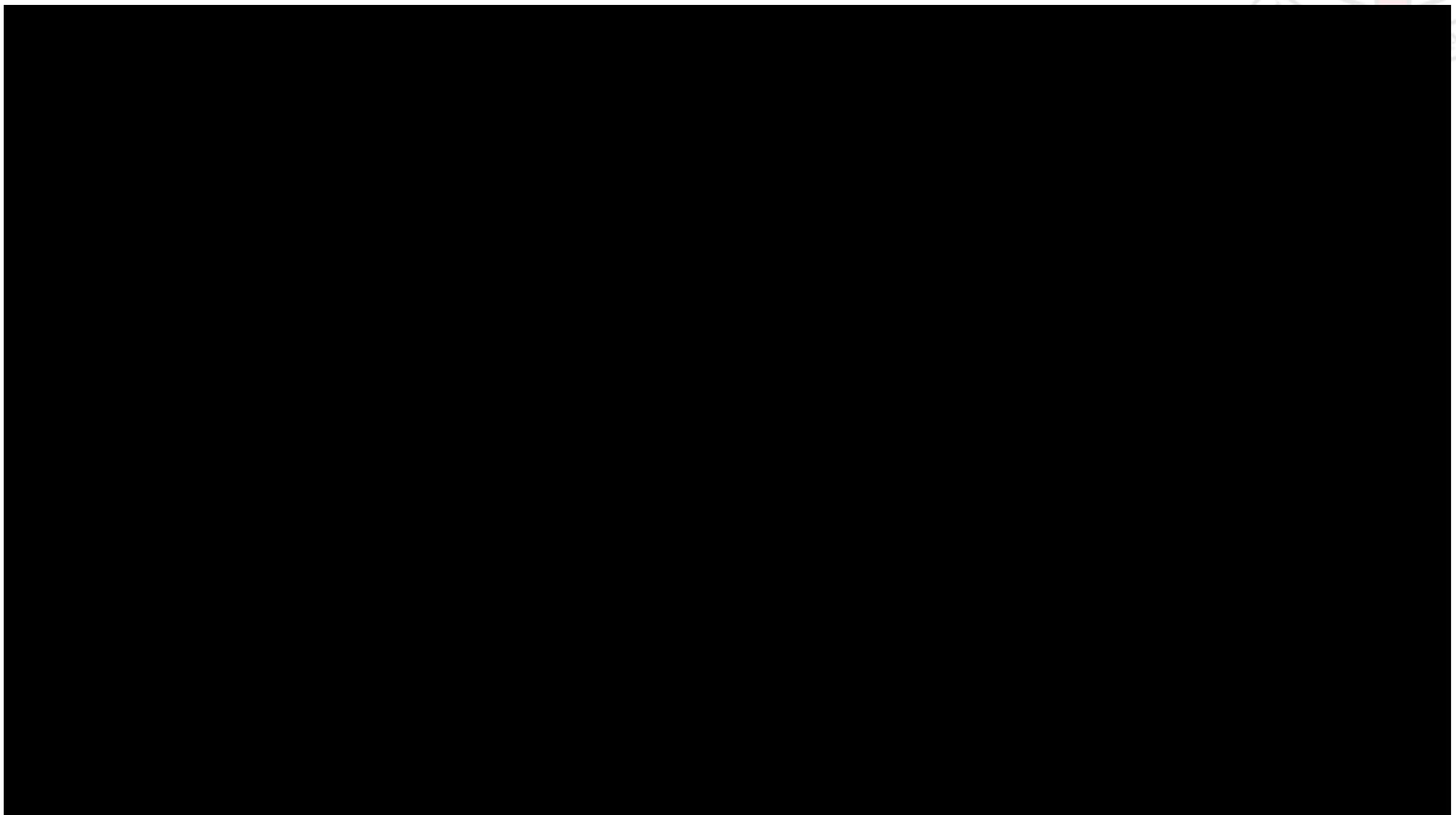
Exploring Objects



How many degrees of freedom does an object have?



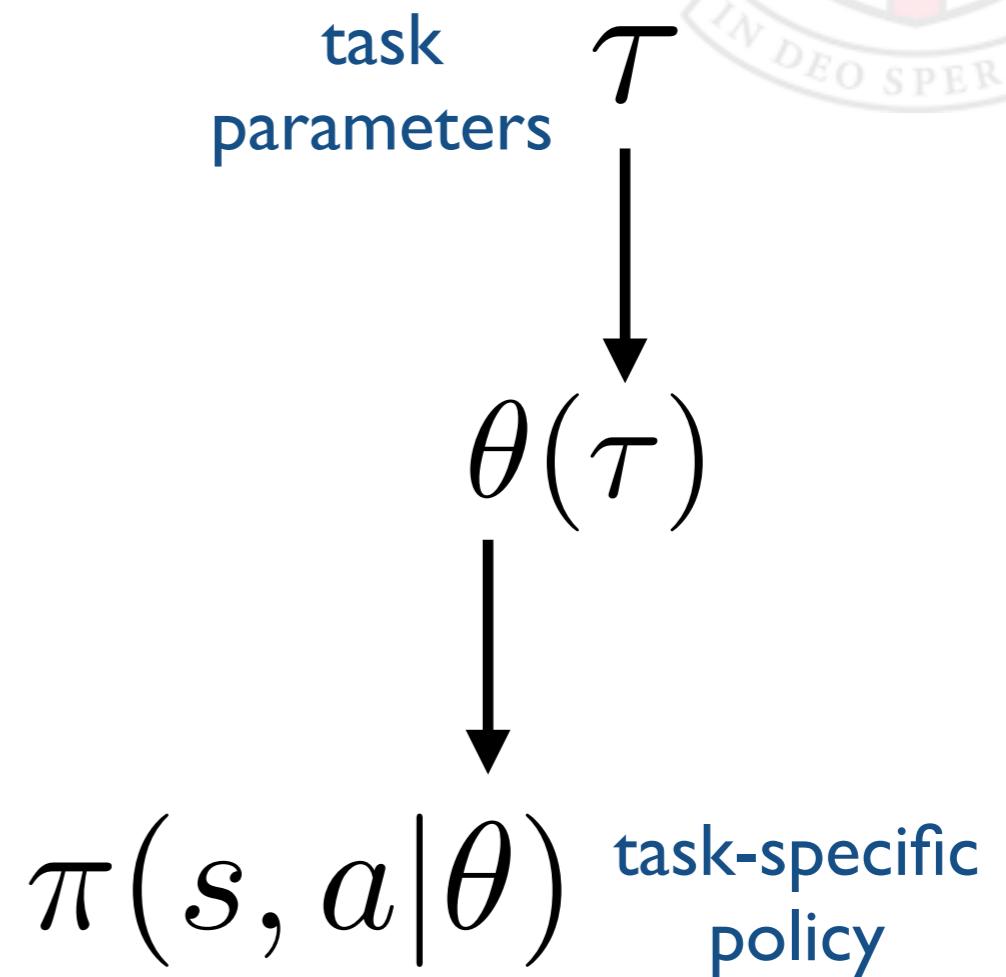
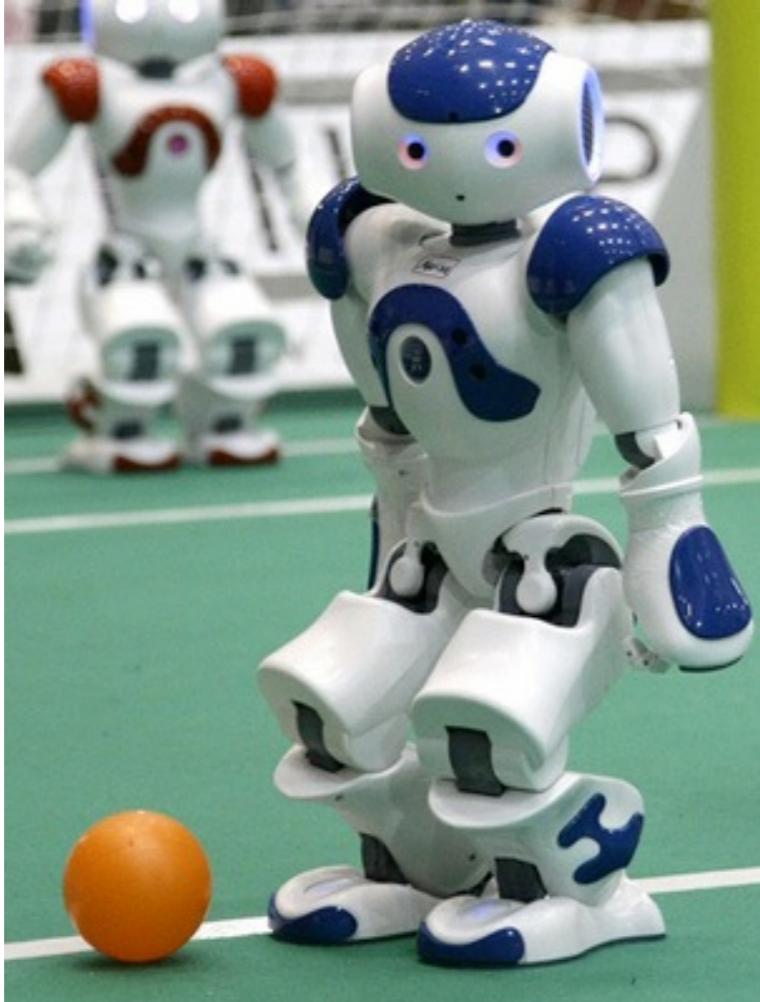
Exploring Objects



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

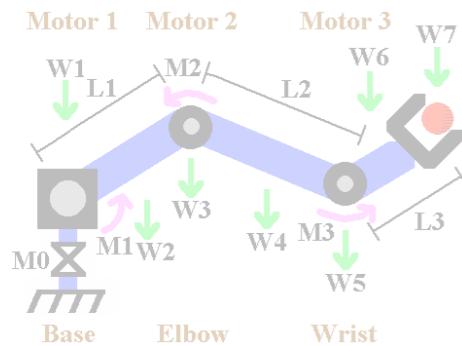
Learning Motor Skills





Robotics

Low-Level



Mid-Level



High-Level

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  )
)
```

High-level Reasoning



Low-level Control

Planning and Reasoning

Given:

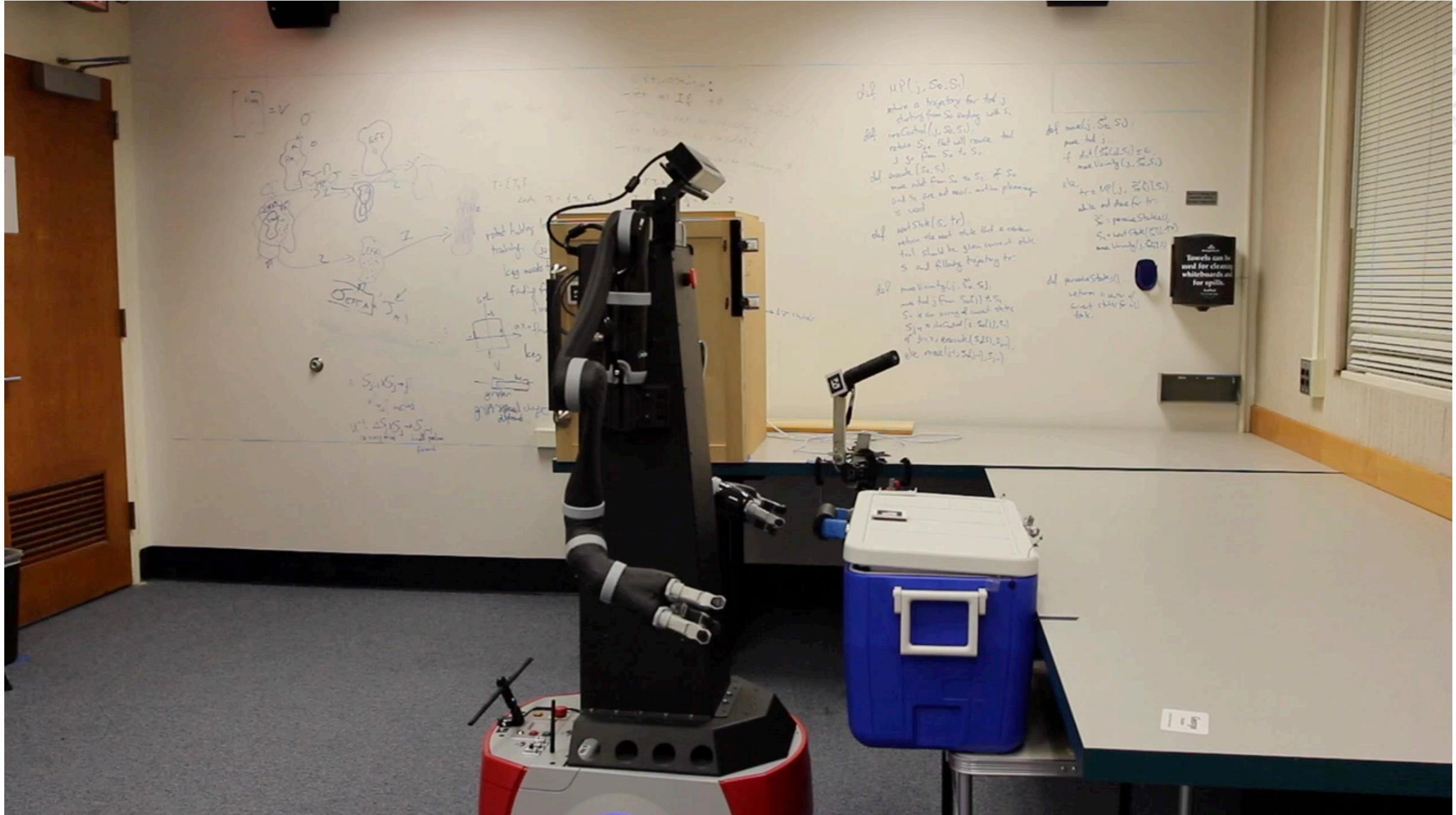
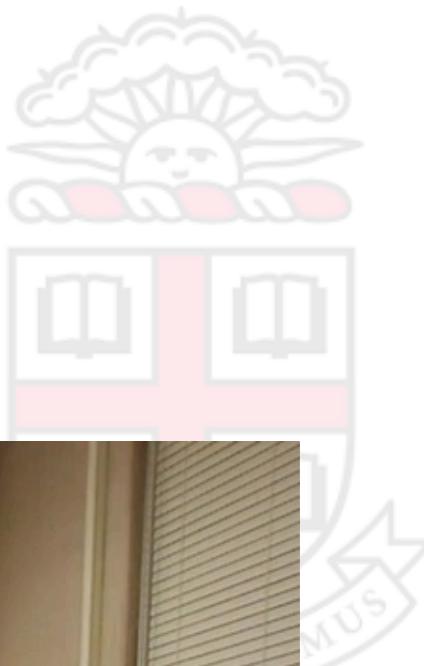
- Localize
- Navigate
- Motion plan
- Move to a given pose
- Recognize objects
- Manipulate objects
- Learning skills

... what next?

Planning using these as a foundation.

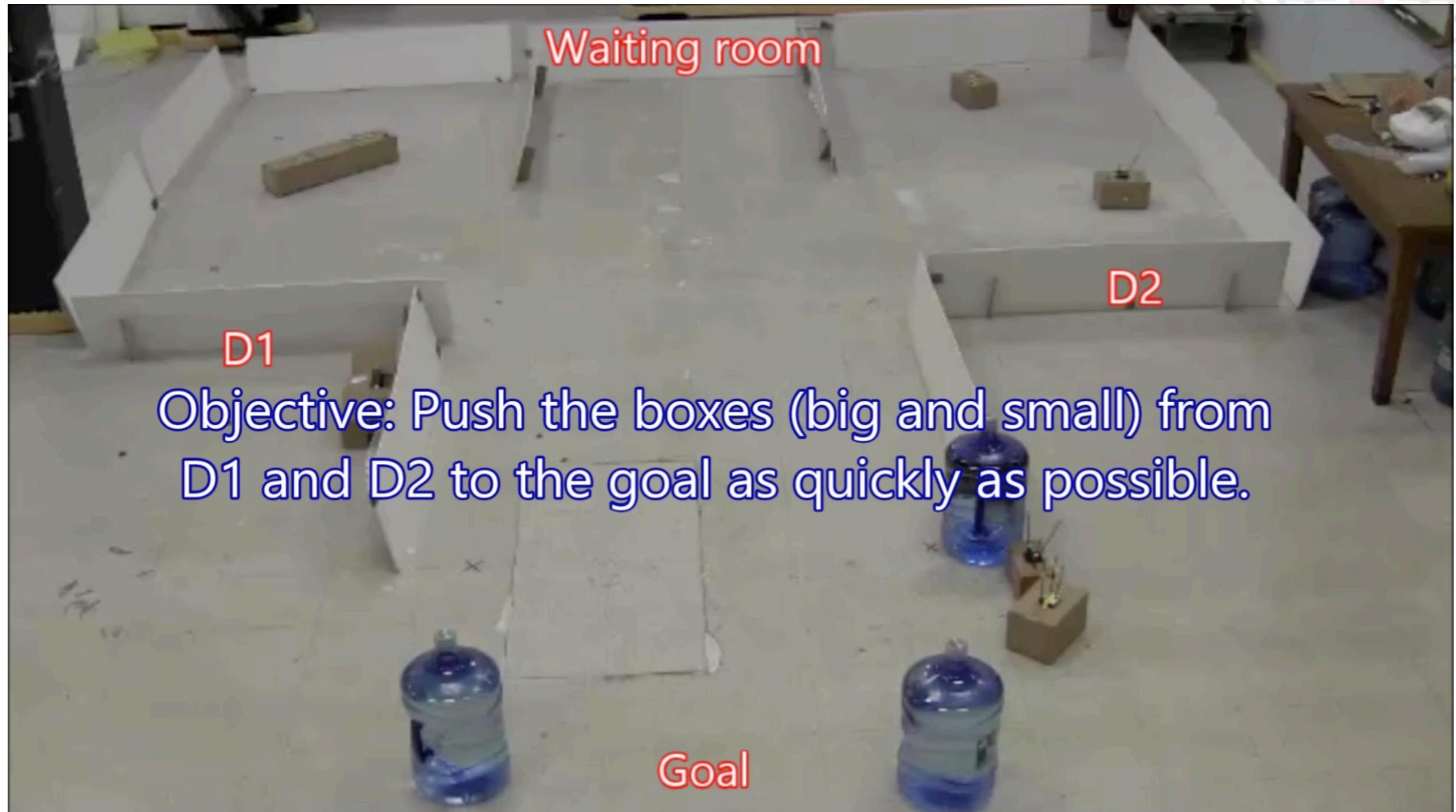
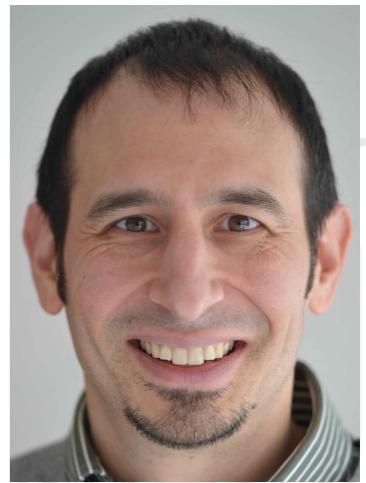


Planning

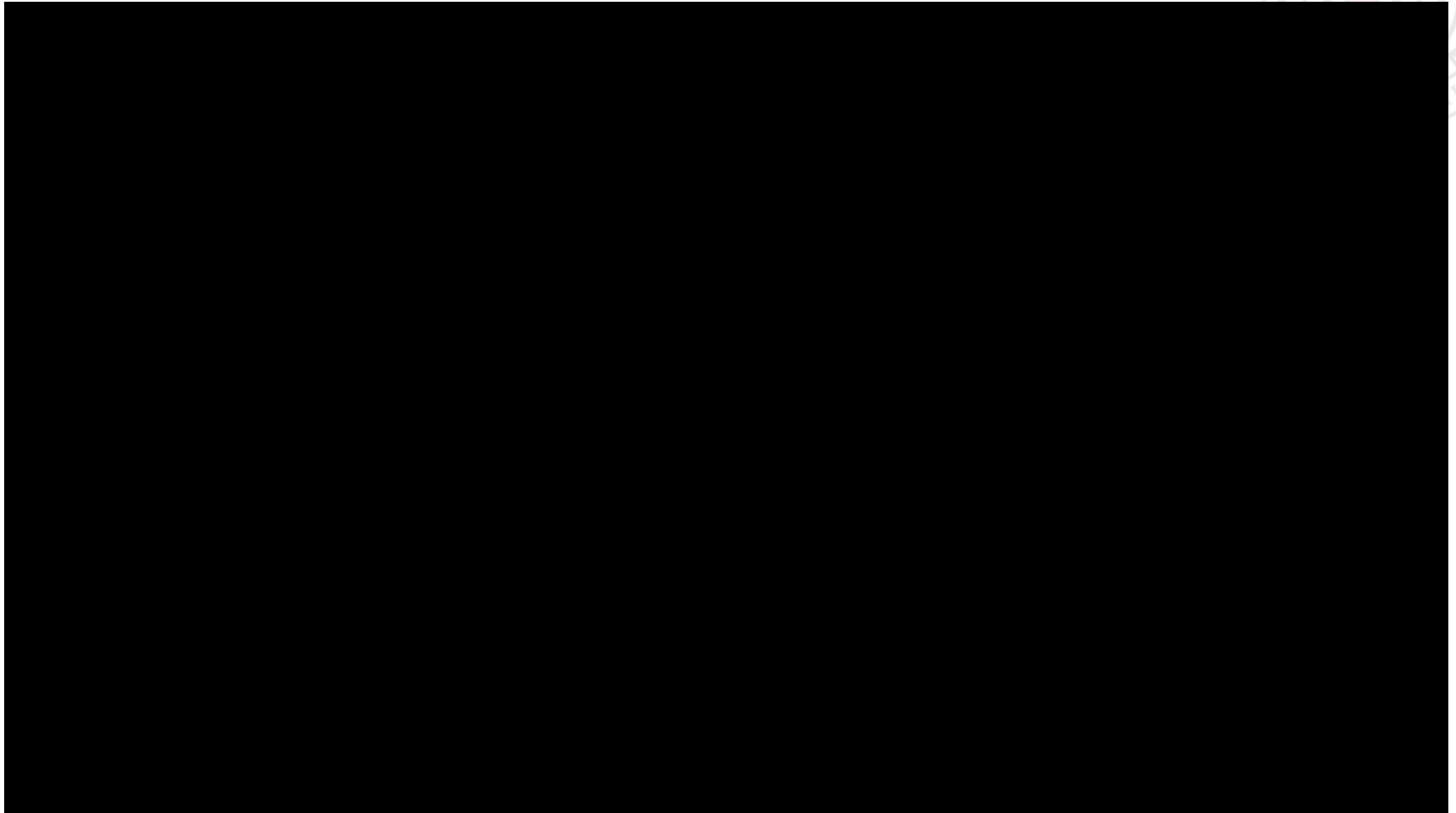


Multi-Robot Planning

Decentralized, partially-observable MDPs

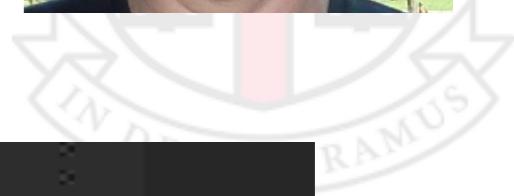


Robocup



Cobots

1,000 km of autonomous operation





Robotics

