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 ∧ KettleFull

Effect: ¬KettleFull ∧ TeaPoured

Low-level Control

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

Low-Level

Mid-Level

High-Level

High-level Reasoning

Low-level Control

```prolog
(:action pick_up
 :parameters ()
 :precondition (and (symbol1) (symbol5) (symbol6) (symbol11))
 :affect (probabilistic
  0.9550 (and)
  0.0041 (and (symbol12) (not (symbol3)))
  (decrease (reward) 53.42)))
)
```
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?
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
1000 Kilometers Of Appearance-Only SLAM

FabMap 2.0
Robotics

Low-Level

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High-level Reasoning

Low-level Control

{(action pick_up2
    :parameters ()
    :precondition (and (symbol11) (symbol15))
    (symbol15) (symbol16) (symbol11))
  :effect (probabilistic
    0.0859 (and)
    0.0041 (and (symbol12) (not (symbol3)))
    (decrease (reward) 53.42)))
}
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
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

High-level Reasoning

Low-level Control

(action pick_up2
  :parameters ()
  :precondition (and (symbol1) (symbol3)
  (symbol5) (symbol6) (symbol11))
  :effect (probabilistic
    0.0659 (and)
    0.0041 (and (symbol12) (not (symbol3)))
    (opencan (reward) 53.42)))
)
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

Objective: Push the boxes (big and small) from D1 and D2 to the goal as quickly as possible.
Robocup

https://www.youtube.com/watch?v=bD-UPoLMoXw
Cobots

1,000 km of autonomous operation
Robotics